DHEC

Promote Protect Prosper

Department of Health and Environmental Control

SOUTH CAROLINA
RISK-BASED CORRECTIVE ACTION
FOR
PETROLEUM RELEASES

Bureau of Land and Waste Management
Underground Storage Tank Program
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LIST OF TERMS USED IN THIS DOCUMENT

- Abatement - Actions taken to mitigate fire and safety hazards and to prevent further migration of hydrocarbons in their vapor, dissolved, or liquid phase.

- Active Remediation - Physical actions taken to reduce the concentration of CoCs to acceptable levels.

- Attenuation - The reduction in concentration of CoCs in the environment with distance and time due to processes that include, but are not limited to, diffusion, dispersion, and absorption.

- Chemical of Concern (CoC) - A specific constituent that is identified for evaluation in the risk assessment process.

- Compliance Point (CP) – see Point(s) of Compliance below.

- Compliance Point Concentration (CPC) - The maximum concentration allowable at the point of compliance in order to protect the exposure point.

- Corrective Action - A subset of site rehabilitation activities conducted to protect human health, safety, and the environment. These activities include recovery of free-product, evaluating risks, evaluating and implementing monitored natural attenuation, making no further action decisions, implementing institutional controls, active remediation, designing and operating cleanup systems and equipment, and monitoring of progress.

- Corrective Action Plan (CAP) - A document outlining proposed corrective actions.

- Department - The South Carolina Department of Health and Environmental Control.

- Direct Exposure Pathway - An exposure pathway where the point of exposure is at the source without a release to any other medium (for example, inhalation of vapors or dermal contact with free product).

- Engineering Controls – Manmade modifications to a site to reduce or eliminate the potential for exposure to a CoC, such as capping or installing a water treatment system on a well.

- Engineering Report (ER) - A document outlining the design and specifications of a corrective action system.

- Exposure - Contact of a receptor(s) with CoC(s). Exposure is quantified as the amount of CoC available at the exchange boundaries, such as skin or lungs, and available for absorption by the human body.

- Exposure Assessment - The determination or estimation, qualitative or quantitative, of the magnitude, frequency, duration, and route of exposure.

- Exposure Pathway - The course CoCs travel from the source area(s) to a receptor. A complete exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., ground water) is included.

- Exposure Point - The point at which it is assumed that a receptor, either potential or actual, can come into contact, either now or in the future, with the CoC. Maximum contaminant levels or other existing water quality standards must be met at the exposure point.

- Exposure Route - The manner in which CoCs come in contact with an organism (i.e., ingestion, inhalation, dermal contact).

- Gas Chromatograph (GC) - An instrument used to determine the levels of CoCs in a vapor, soil or ground water sample.

- Initial Ground Water Assessment (IGWA) – An assessment to determine soil and ground water CoCs by the installation of one monitoring well.

- Indirect Exposure Pathways - An exposure pathway with at least one intermediate release to any media between the source and the point of exposure (e.g., leaching of CoCs from soil to ground water).

- Institutional Controls - The restriction on use or access (e.g., existing deed restrictions, restrictive zoning and conditions listed in the registry of releases) to a site or facility to eliminate or minimize potential exposure to CoCs.

- Maximum Contaminant Level (MCL) - A standard for drinking water established by the USEPA under the Safe Drinking Water Act. The MCL is the maximum permissible level of CoC in water that is used as a drinking water supply.

- Monitored Natural Attenuation (MNA) - The verifiable reduction of CoC through naturally occurring microbial activity or attenuation mechanisms.

- Operator – An entity as defined in Section 44-2-20(10) of the State Underground Petroleum Environmental Response Bank Act.

- Organic Vapor Analyzer (OVA) - A field instrument used to measure the organic vapors present in a sample of soil or ground water. A Photo Ionization Detector (PID) is a type of OVA.

- Owner – An entity as defined in Section 44-2-20(12) of the State Underground Petroleum Response Bank Act.

- Point(s) of Compliance - A location(s) selected between the source area and the exposure point(s) where CoCs must be at or below the determined target levels (CPC) in the specified media (e.g., soil, ground water, air).

- Point(s) of Verification - A location(s) selected for monitoring to verify a decrease in a CoC as a result of corrective action.

- Reasonably Anticipated Future Use - Future land use which can be predicted given current use, local government planning, and zoning.

- Receptors - Persons, structures, utilities, surface water bodies, sensitive habitats, water supply wells, or any living organisms that are, or may be, affected by a release.

- Representative Concentration:

    In Air - The maximum CoC concentration obtained during the most recent sampling event.

    In Groundwater - The maximum CoC concentration obtained during the most recent sampling event.

    In Soil - The maximum CoC concentration obtained during the most recent sampling event for the ingestion and dermal contact pathways. For the soil reaching groundwater pathway, the average of up to two soil samples with the highest non-zero concentrations from each source area will be used to compare with the screening levels.

- Risk Assessment - An analysis of the potential for adverse health effects caused by CoC to determine the need for corrective action. Also used to develop target levels or cleanup goals if corrective action is required.

- Risk Reduction - The lowering or elimination of the level of risk posed to human health or the environment through initial response actions, corrective actions, or institutional or engineering controls.

- Risk-Based Screening Level (RBSL) - Risk based action level for a CoC based on a 10^{-6} target risk. RBSLs are not site-specific.

- Separation Distance – The vertical distance between the depth of worst case soil contamination and the depth to the top of the water table.

- Site Assessment - The collection of data on ground-water quality and potential receptors, subsurface geology, hydrology, and site characteristics to determine the extent of the migration of the CoCs and action levels of the CoCs to support remedial action decisions.

- Site Classification - A qualitative evaluation of a site based on known or readily available information. Associated with site classifications are initial response actions that are to be implemented simultaneously with the RBCA process. Sites are re-classified as actions are taken to resolve concerns or as additional information becomes available.

- Sensitive Habitat - Fresh and salt-water fisheries, fish habitats including shellfish areas, coastal and inland wetlands, and habitats of threatened or endangered species.

- Site-Specific Target Level (SSTL) - Risk-based corrective action target level for a CoC developed for a particular site under the Tier 2 and Tier 3 evaluations.

- Source Area - Either the location of free-phase hydrocarbons or the location of the highest concentration of the CoC in soil, vapor, or groundwater.

- Tier I Assessment – Previously known as a Standard Limited Assessment (SLA). A defined scope of work, consisting of three monitoring wells and eight soil borings, to determine soil and groundwater contamination, hydraulic properties and risk.

- Tier 1 Evaluation - A risk-based analysis where non-site-specific values based on conservative exposure factors (RBSL), potential exposure pathways, and land use are evaluated to determine appropriate actions. An Initial Ground-Water Assessment, Tier I Assessment, or Tier II Assessment may include a Tier 1 Evaluation for soil and ground water, if not previously completed.

- Tier II Assessment – Previously known as a Rapid Assessment (RA). A scope of work proposed by a certified site rehabilitation contractor, consisting of established tasks/components in order to provide a comprehensive risk-based assessment of soil and ground water contamination, hydraulic properties and risk.

- Tier 2 Evaluation - A risk-based analysis applying the RBSL at the exposure point, development of SSTLs for potential indirect exposure pathways based on site-specific conditions, and establishment of point(s) of compliance. A Tier I Assessment or Tier II Assessment may include a Tier 2 Evaluation for vapor, soil, and ground water, if not previously completed.

- Tier III Assessment – A scope of work proposed by a certified site rehabilitation contractor, consisting of established tasks/components in order to further refine the site specific target levels for potential and indirect exposure pathways established from a previously completed Tier II Assessment. A Tier III Assessment would typically incorporate a more sophisticated fate and transport model. Additional monitoring point(s) to further define the geological conditions or collect additional data may also be needed to refine other naturally occurring conditions at the facility or receptor(s).

- Tier 3 Evaluation - A risk-based analysis to develop values for potential direct and indirect exposure pathways at the exposure point based on site-specific conditions. A Tier II Assessment may include a Tier 3 Evaluation for vapor, soil, and ground water.

The following table gives a comparison of the three tier evaluations:

		Tier 1 Evaluation	Tier 2 Evaluation	Tier 3 Evaluation
Screening Levels		RBSLs	RBSLs / SSTLs	RBSLs / SSTLs
Representative Concentrations - Air		Maximum CoC concentrations	Maximum CoC concentrations	Maximum CoC concentrations
Representative Concentrations - Soil	Ingestion, Inhalation & Dermal Contact	Maximum CoC concentrations	Maximum CoC concentrations	Maximum CoC concentrations
	Leachate	Maximum Concentration or average of samples	Average of two samples	Average of two samples
Representative Concentrations - Water		Maximum CoC concentrations	Maximum CoC concentrations	Maximum CoC concentrations
Target Risk		$1x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$ or as approved
Hazard Quotient		1	1	1 or as approved
Exposure Factors		Not Applicable	Not Applicable	Default or Site-specific
Fate & Transport		Not Applicable	Domenico or equivalent	Numerical Models
Leachate		Not Applicable	Leachability Model	Leachability or other
Air		Not Applicable	Vapor Models	Vapor Models
Main Steps		Compare RBSLs, Site Conceptual Exposure Model, Receptors, Data requirements	Establish: Exposure Points, Points of Compliance and SSTLs	Further refine SSTLs based on additional data & modeling
Locations where RBSLs are applied		Source Area(s)	Exposure Point(s)	Exposure Point(s)
Data Collection		Source Area Characterization	Complete Plume Delineation	Detailed site-specific biodegradation study
Outcome of Evaluation		NFA, Tier 2 Evaluation, Emergency Action	NFA, CNFA, Corrective Action, Tier 3 Evaluation	CNFA, NFA, Corrective Action

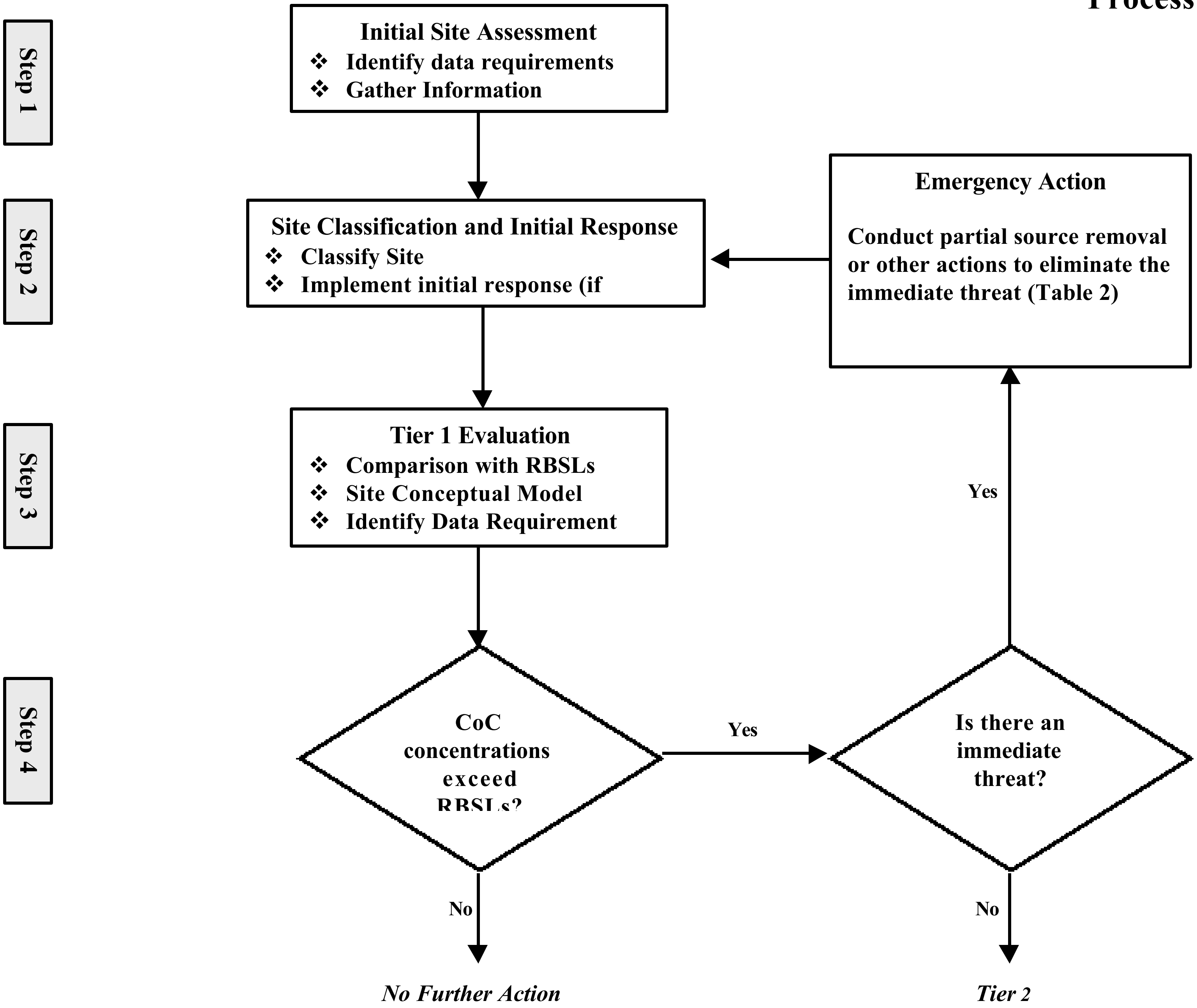
I. RISK-BASED DECISION MAKING FOR PETROLEUM RELEASES

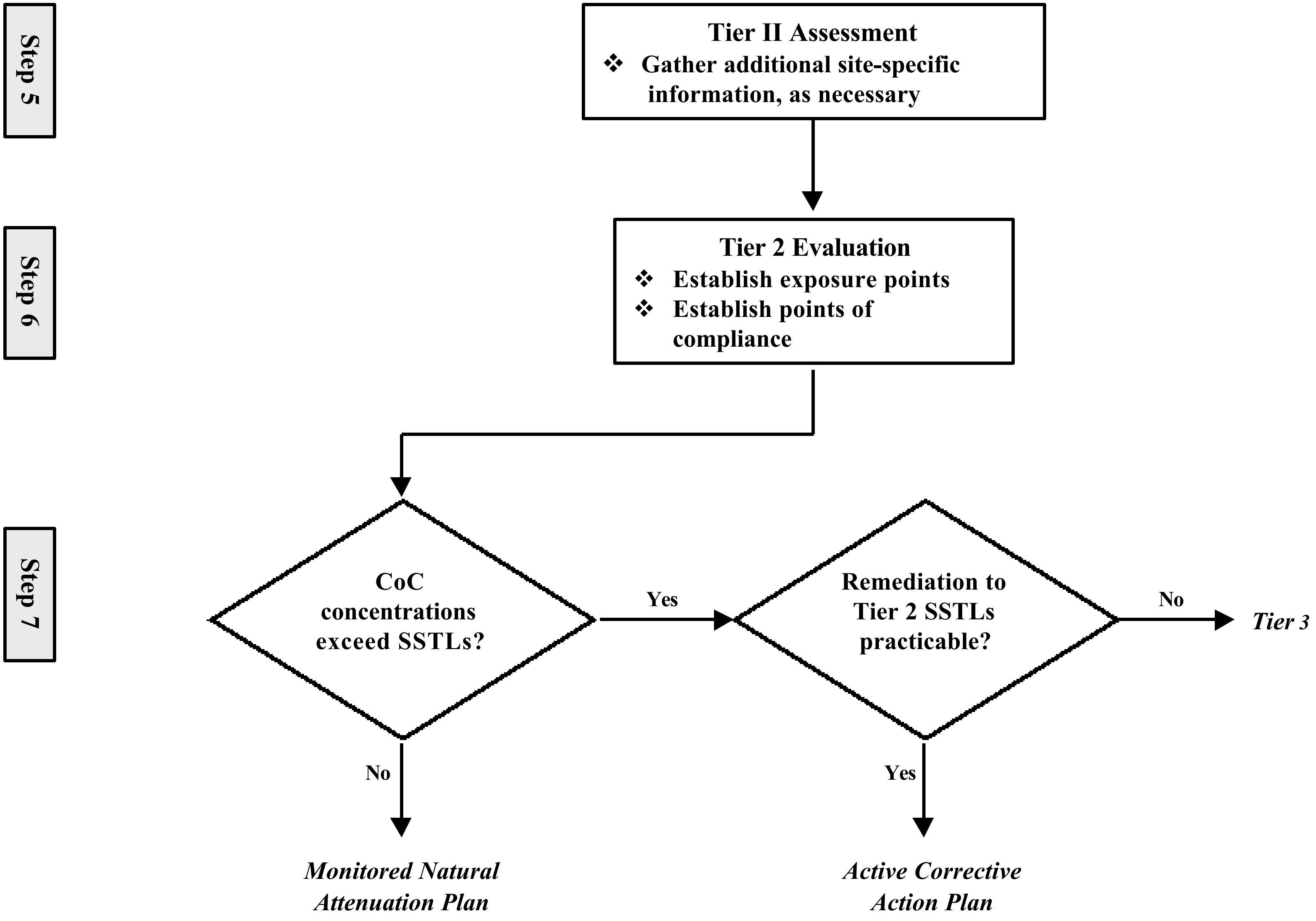
The following technical criteria are provided to assist Underground Storage Tank (UST) owners or operators and their contractors and the agency in making risk-based decisions concerning corrective action for releases of petroleum and petroleum products. Where risk-based decision making is incorporated into the corrective action process, the result is called risk-based corrective action (RBCA). The RBCA decision process takes into account the current and potential future risk posed by releases. The risk is defined by using site-specific data concerning receptors; exposure potential; site hydrogeology; and the type, amount, and toxicity of the Chemicals of Concern (CoCs). Ensuring that corrective actions are protective of human health and the environment is the objective of the risk-based approach.

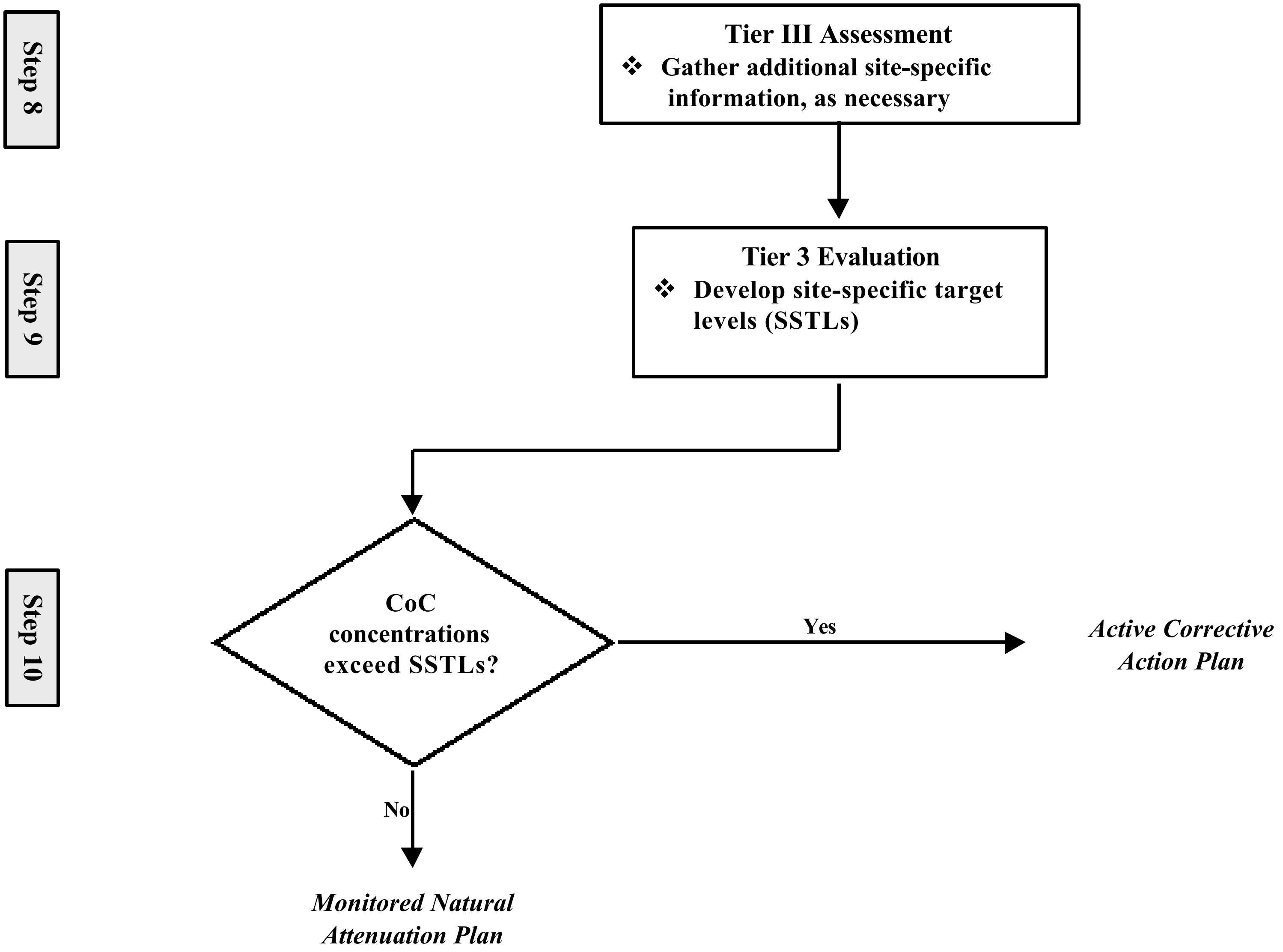
This guidance document should be used to augment the requirements of the SUPERB Site Rehabilitation and Fund Access Regulation (R.61-98). It specifically outlines the process of evaluating the risk of direct and indirect exposure for each CoC due to ingestion, inhalation, dermal contact and accumulation of explosive vapor levels in buildings, structures, or utilities. This document outlines a three-tiered approach for evaluation of a petroleum release integrating risk assessment, risk management, site assessment, monitoring, and corrective action selection for petroleum releases specific to South Carolina. Figure 1 shows a flow chart of the SCRBCA process. For additional understanding on this topic, please see the references listed in Appendix G.

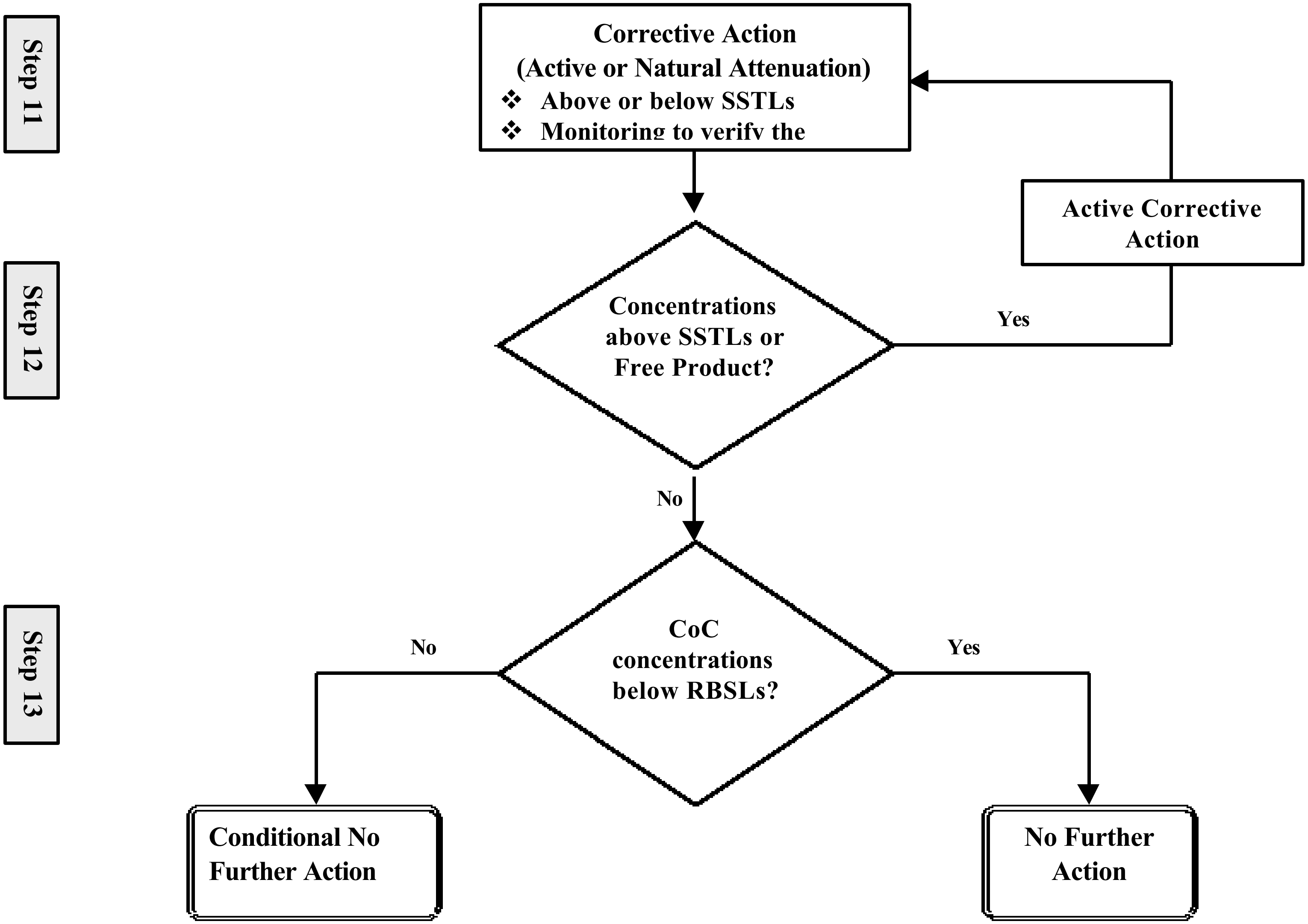
In response to releases from USTs, owners or operators must take certain initial steps: prevent further releases, control fire and explosion hazards, and remove free product pursuant to the UST Control Regulations, R.61-92. Investigation plans, RBCA evaluation reports, Corrective Action Plans, and Engineering Reports must be approved by the Department, as necessary and in accordance with applicable guidance and regulations. All site rehabilitation activities related to UST releases must be performed by a SCDHEC certified site rehabilitation contractor as required by the SUPERB Fund Access and Site Rehabilitation Regulations, R.61-98.

RBCA Process




Step 5
Tier II Assessment
❖ Gather additional site-specific information, as necessary
Step 6
Tier 2 Evaluation
❖ Establish exposure points
❖ Establish points of compliance
Step 7
CoC concentrations exceed SSTLs?
Yes
Remediation to Tier 2 SSTLs practicable?
No
Tier 3
No
Monitored Natural Attenuation Plan
Yes
Active Corrective Action Plan


Step 8
Step 9
Step 10
Tier III Assessment
❖ Gather additional site-specific information, as necessary
Tier 3 Evaluation
❖ Develop site-specific target levels (SSTLs)
CoC concentrations exceed SSTLs?
Yes
Active Corrective Action Plan
No
Monitored Natural Attenuation Plan


Step 11
Step 12
Step 13
Corrective Action
(Active or Natural Attenuation)
❖ Above or below SSTLs
❖ Monitoring to verify the
Active Corrective Action
Concentrations above SSTLs or Free Product?
Yes
No
CoC concentrations below RBSLs?
No
Yes
Conditional No Further Action
No Further Action

II. RISK-BASED CORRECTIVE ACTION PROCEDURES

STEP 1 - SITE ASSESSMENT

The information necessary for determining if emergency action is appropriate and for comparing concentration of CoCs to the RBSL must be obtained. The Initial Ground-Water Assessment (IGWA) and Tier I Assessment (former Standard Limited Assessment) guidance documents outline the minimum information necessary for completion of soil and ground-water assessment and a Tier 1 risk evaluation. In general, the information to be obtained during the Tier 1 evaluation may include:

- A review of historical records of site activities and past releases;

- Quantification of the CoC. For petroleum releases, based on toxicity, mobility, persistence, and presence in material released, selected CoCs are:

  For all gasoline, diesel, kerosene: benzene, toluene, ethylbenzene, xylenes, MTBE, PAH's (total naphthalene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)flouranthene, chrysene, and dibenz(a-h)anthracene). EDB and lead will be investigated if tanks were in operation prior to 1991;

  For used oil add: arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver;

- Quantification of biological indicator parameters such as dissolved oxygen, nitrate, ferrous iron and sulfate. Table 1 gives selected parameters, suggested analytical methods and the reporting limits;

- Location of primary source(s) of CoCs:
  - USTs, product lines, dispensers, service bays, etc.;

- Location of secondary source(s) of CoCs:
  - free-product, soil with concentrations above RBSLs, etc.;

- Location of maximum concentration of CoCs in soil and ground water;

- Determination of regional or site-specific hydrogeologic conditions (e.g., depth to ground water, flow direction, gradient, ambient ground water quality, ground-water flow velocity);

- Location of current and reasonable future receptors within 1,000 feet of the site. All drinking water wells within a radius of 250 feet of the site shall be sampled for appropriate CoCs;

- Identification of potential significant transport and exposure pathways. A complete exposure pathway includes: 1) a source and mechanism for CoC release into the environment, 2) a transport medium (e.g., air, soil, ground water, vapor migration through soil and utilities) for the CoC to move from the source to the receptor, 3) a point of potential contact of the receptor with the medium (points of exposure such as drinking water wells, surface water bodies), and 4) an exposure route or means for taking the CoC into the body (e.g., ingestion, inhalation, dermal contact);

Table 1

Analytical Methods and Reporting Limits for Selected Parameters

Product	Soil Samples			Water Samples		
	Parameters	Analytical* Method	Method Detection Limit	Parameters	Analytical* Method	Method Detection Limit
Gasoline Diesel Kerosene	BTEX	5035** with 8260B•	1 µg/Kg	BTEX	5030B** with 8260B•	1 µg/L
				EDB	8011	0.02 µg/L
	Total Naphthalenes	5035** with 8260B•	5 µg/Kg	M*t*BE	5030B**with 8260B•	5 µg/L
				Total Naphthalenes	5030B** with 8260B•	5 µg/L
	Other PAHs	3550B** with 8270C, 8100, or 8310	66 µg/Kg	Other PAHs	3510C** with 8270C, 8100, or 8310	10 µg/L
	Biological Indicator Parameters			Ferrous Iron Nitrate Sulfate Dissolved Oxygen	3500D 9056 or 9210 9056 or 9038 Field Measurement	1 µg/L 100 µg/L 100 µg/L 100 µg/L
For Leaded Gasoline **ADD**	Total Lead	6010B or 7421	5 µg/Kg	Total Lead	7421 or 6010B	3 µg/L
For Waste or Used Oil **ADD**	Metals	AA (7000 series for Hg) ICP (6010B)	10 µg/Kg	Metals	AA(7000 series for Hg) ICP (6010B)	5 µg/L

All Methods are SW-846 Methods except Method 3500D for Ferrous Iron

• Please note that the UST Program does not allow equivalent methods for these VOC analyses.

* Any equivalent EPA approved method that will achieve the same method detection limits can be substituted.

** Other extraction methods may be used if the laboratory is certified for the extraction and determinative method.

Other PAHs include:	Benzo(a)anthracene, Benzo(b)flouranthene, Benzo(k)flouranthene, Chrysene, Dibenz(a,h)anthracene
Metals include:	Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver
AA-ICP:	Atomic Absorption - Inductively Coupled Plasma
Total Lead and EDB:	Must be sampled if tanks were in operation prior to 1991.

Determination of current and reasonably anticipated future use of the property, ground water, surface water, and sensitive habitats for the site and adjacent properties. Use of property shall be determined based on factors such as: zoning laws; comprehensive infrastructure such as transportation and public utilities; site location in relation to urban, residential, commercial, industrial, agricultural, and recreational areas; Federal/State land use designation; historical or recent development patterns; and location of wellhead protection areas;

- Documentation, if available, of the changes in concentration of CoCs over time (i.e., stable, increasing, decreasing);

- Documentation, if appropriate, of concentration of CoCs measured at point(s) of exposure (e.g., concentration of CoCs in a nearby drinking water well, vapor concentration of CoCs in nearby utilities); and

- Collection of air or water quality samples, as appropriate, from any receptor (well, underground structure, water body) that has a potential of being impacted by virtue of its proximity to the source.

STEP 2 - SITE PRIORITY CLASSIFICATION

Based on initial release information and subsequently upon completion of each tier evaluation, the release is classified by DHEC into categories based on the current and projected degree of risk to human health and the environment. The highest priority classification is for those releases that pose an emergency. The second priority classification is for those releases that pose a significant near term (0 to 1 year) threat, the third priority classification is for those releases where there is a short term (1 to 2 years) threat, the fourth priority classification is for those releases where there is a long term (> 2 years) threat to human health or the environment. The fifth priority classification is for releases that do not meet any of the characteristics of the earlier priorities, or where there is no current demonstrable threat to human health or the environment but where data indicate CoC concentrations are above the RBSLs and further assessment is needed. Ground-water travel times are calculated from the monitoring well closest to the exposure point that contains concentration of CoCs above the RBSLs.

Prioritization/classification is an on-going process based on available information. Releases may be re-classified subsequent to abatement, further assessment information, and remedial actions. Please see Appendix A for the definitions of each class of the priority classification system.

Typical release scenarios and response actions to eliminate any immediate threat are provided in Table 2. Emergency Action to eliminate immediate exposure is required. The Underground Storage Tank Program should be notified at (803) 898-4350 or, when necessary, and emergency can be reported directly to the Emergency Response Program at 1-888-481-0125 or (803) 253-6488. Appropriate actions must be implemented as soon as possible to eliminate an immediate threat.

Table 2

Potential Initial Response Actions to Eliminate Immediate Threat for Typical Release Scenarios

Scenario	Potential Initial Response
Explosive levels or concentrations of vapor are present in a residence or other building	Evacuate occupants, begin abatement measures such as ventilation
Explosive levels are present in the subsurface utility system	Evacuate immediate vicinity, begin abatement measures such as ventilation
Free-phase product is present in significant quantities at ground surface, on surface water bodies, or in utilities	Prevent further free-phase product migration, institute recovery, monitor vapor concentrations
An active water supply well, water supply line, or a public water is impacted or immediately threatened	Notify users, provide alternate water supply, treat water point of use
A sensitive habitat or sensitive resources are impacted	Minimize extent of impact by containment measures and implement habitat management to minimize exposure

STEP 3 - TIER 1 EVALUATION

Data obtained from a Tier I Assessment (former SLA) requires three sub-steps to complete the Tier 1 Evaluation: 1) comparison with the RBSL, 2) the development of a site conceptual exposure model, and 3) identification of data required to characterize the complete and potential pathways identified in the site conceptual exposure model. A complete exposure pathway exists where a mechanism allows a receptor to be exposed to the CoC.

Data obtained from an IGWA allows comparison of CoC concentrations to the soil and ground water RBSLs to determine if additional a Tier 1 or Tier 2 evaluation is required.

1) Comparison with RBSL

For a Tier 1 Risk Evaluation, it is assumed that all exposure points are located in the source area. CoC concentrations should be compared with the values provided in the RBSL Look-Up Tables in Appendix B for the ground-water ingestion, soil leaching to ground water, vapor inhalation, and soil ingestion pathways. For other chemicals of concern not included in Appendix B, the RBSLs may be calculated based on a carcinogenic risk of 10^{-6} and a hazard index of 1. As the toxicity of Total Petroleum Hydrocarbon (TPH) analyses cannot be quantified, it cannot be used in the risk decision making process. Each CoC is evaluated separately for each exposure route as SCRBCA does not consider the additive effect of risk from different CoCs and different routes of exposure.

Representative concentrations of CoCs in affected media are determined by the following:

- **Air:** The maximum CoC vapor concentration obtained during the most recent sampling event should be used. Historical sampling events can be used to establish trends.

- **Ground Water:** The maximum CoC concentration obtained during the most recent sampling event should be used. Historical sampling events can be used to establish trends.

- **Soil:** The maximum CoC concentration obtained during the last sampling event should be used for the ingestion and dermal contact pathways. For the soil leaching to ground water pathway, the average of two soil sample results with the highest non-zero concentrations from each source will be compared with RBSLs.

2) Site Conceptual Exposure Model

A site conceptual exposure model uses information about the following to identify all complete and potential exposure pathways:

Release information:

- Pertinent release information may include, but is not limited to: the historical use of the property where the release occurred, the approximate age of the release, and the properties of the CoC (e.g., solubility, volatility) that were released.

Characteristics of the site:

- Pertinent site characteristics may include, but are not limited to: the soil type, depth to ground water, bulk density, porosity, water content, hydraulic gradient, ground-water flow direction, seepage velocity, fractional organic carbon and the physical distribution of each CoC around the source.

Proximity of potential receptors and their characteristics:

- The construction specifications (e.g., depth, diameter, and material of construction of a storm sewer) of all potential man-made receptors should be identified.

- Location of all natural receptors (e.g., rivers, lakes, marshes, etc.) within 1,000 feet.

Current land use of all affected properties:

- For each property that is impacted, may potentially become impacted, or is adjacent to a potentially impacted property, the current land use should be identified (e.g., vacant lot, restaurant, school, residence, factory).

Applicable zoning or land use ordinances:

- The local city or county administrative authorities should be contacted for information pertaining to any restrictive zoning and land use ordinances. Zoning ordinances set broad-scale restrictions on property development such as residential, commercial, or industrial. Land use ordinances may establish smaller scale restrictions such as disallowing the installation of drinking water or irrigation wells. A photocopy of the applicable sections of the ordinances should be provided. If a copy cannot be obtained, the ordinance number and the name, phone number, and business address of the appropriate city or county authorities should be provided with the relevant information.

Based on the estimated age of the release, known distribution of the CoCs, and the potential for migration, all complete and potential exposure pathways should be identified and summarized for land use (current and future conditions). For example, drinking water wells may not currently exist but ground water may reasonably become a source of drinking water. The following potential exposure pathways should be considered for evaluation:

- **Air**
    - inhalation of ambient vapors
    - explosive hazard

- **Surface Water** (e.g., lake, river, stream, ditch, marsh)
    - ingestion
    - dermal contact
    - volatile inhalation

- **Ground Water**
    - ingestion
    - dermal contact
    - volatile inhalation

- **Surficial Soil** (impacted soil located <3 feet below land surface or exposed at surface)
    - ingestion
    - dermal contact
    - volatile inhalation
    - leaching to ground water

- **Subsurface Soil** (impacted soil located >3 feet below land surface)
    - ingestion (during excavation)
    - dermal contact (during excavation)
    - volatile inhalation (during excavation)
    - leaching to ground water

Exposure routes and pathway summarization for the site conceptual model are shown in Tables 3 and 4.

3) Identify Data Requirements

For each complete or potential exposure pathway identified in the site conceptual model, identify the data necessary to characterize the migration potential along the pathway and to quantify the potential impact. For example, if the accumulation of vapors in a utility is a concern, data may be appropriate to characterize the transport of the CoC from the source to the utilities via ground water, the extent of volatilization from the ground water, the transport of vapors from the ground water to the utility, and the construction specifications (material of construction and types of seals) of the utility. These data requirements would then become an integral part of a Tier II assessment. The site conceptual model format for various media of exposure should be summarized in Tables 3 and 4.

STEP 4 - TIER 1 ACTION

Once the Tier 1 evaluation or Tier I assessment (former SLA) is completed, three decision options are available for consideration based on the CoC concentrations:

1) No Further Action

If the representative concentrations (please see step 3 for an explanation of the representative concentrations) of the CoCs are below the RBSLs, further assessment and/or cleanup is not necessary. Please see the no further action option in Section III.

2) Emergency Action

Typical release scenarios and response actions to eliminate any immediate threat are provided in Table 2. Emergency Action to eliminate immediate exposure is required. The Underground Storage Tank Program should be notified at (803) 898-4350, or when necessary, an emergency can be reported directly to the Emergency Response Program at 1-888-481-0125 or (803) 253-6488. Appropriate actions must be implemented as soon as possible to eliminate an immediate threat.

3) Tier II Assessment

If the concentrations of the CoCs are above the RBSLs, a Tier 2 investigation using a Tier II Assessment (former Rapid Assessment) is warranted under the following conditions:

- If the SSTL developed under the Tier 2 investigation are anticipated to be significantly different from the Tier 1 RBSL (concentration of CoC exceeds the RBSL but it is predicted that the use of site-specific data will allow different site-specific cleanup goals to be determined);

Table 3

Site Conceptual Model - CURRENT LAND USE

Media (for exposure)	Exposure Route	Pathway Selected for Evaluation? (Yes or No)	Exposure point or Reason for Non-Selection	Data Requirements (IF pathway selected)
Air	Inhalation	Yes No		
	Explosion Hazard	Yes No		
Ground-Water	Ingestion	Yes No		
	Dermal Contact	Yes No		
	Inhalation	Yes No		
Surface Water	Ingestion	Yes No		
	Dermal contact	Yes No		
	Inhalation	Yes No		
Surficial Soil	Ingestion	Yes No		
	Dermal contact	Yes No		
	Inhalation	Yes No		
	Leaching to Ground-Water	Yes No		
Subsurface Soil	Ingestion	Yes No		
	Dermal contact	Yes No		
	Inhalation	Yes No		
	Leaching to Ground-Water	Yes No		

Table 4

Site Conceptual Model - FUTURE LAND USE

Media (for exposure)	Exposure Route	Pathway Selected for Evaluation? (Yes or No)	Exposure point or Reason for Non-Selection	Data Requirements (IF pathway selected)
Air	Inhalation	Yes No		
	Explosion Hazard	Yes No		
Ground-Water	Ingestion	Yes No		
	Dermal Contact	Yes No		
	Inhalation	Yes No		
Surface Water	Ingestion	Yes No		
	Dermal contact	Yes No		
	Inhalation	Yes No		
Surficial Soil	Ingestion	Yes No		
	Dermal contact	Yes No		
	Inhalation	Yes No		
	Leaching to Ground-Water	Yes No		
Subsurface Soil	Ingestion	Yes No		
	Dermal contact	Yes No		
	Inhalation	Yes No		
	Leaching to Ground-Water	Yes No		

- If the cost of remedial action to reach RBSL will likely be greater than Tier 2 evaluation (data collection, analysis, review, etc.) and subsequent remedial action; and

- The approach or assumptions used to derive the Tier 1 goals are not appropriate for conditions at the site.

STEP 5 - TIER II ASSESSMENT

If Tier II assessment is warranted to fully evaluate the current and future exposure pathways identified in the site conceptual model, a Tier II Assessment (former Rapid Assessment) Plan to conduct a Tier 2 evaluation should be submitted.

A Tier II Assessment includes:

- determination of the site-specific hydrologic conditions;
- determination of horizontal and vertical extent of each CoC above the RBSL, as appropriate;
- determination of changes in concentrations of each CoC over time (i.e., increasing, stable, or decreasing with time);
- determination of concentrations of each CoC measured at exposure points (e.g., in a nearby drinking water well, vapor concentration of nearby utilities); and
- evaluation of fate and transport of each CoC.

Additional site assessment may be required to fully evaluate the current and future exposure pathways identified in the Tier 1 evaluation. The Tier II Assessment (former Rapid Assessment) document outlines a comprehensive site assessment approach for obtaining the additional information necessary for a Tier 2 evaluation.

STEP 6 - TIER 2 EVALUATION

The Tier 2 risk evaluation consists of three sub-steps: 1) establishing exposure point(s), 2) establishing the site-specific points of compliance, and 3) calculating the corresponding SSTL for each CoC for identified points of compliance and verification.

1) Establish the exposure point(s)

An exposure point is that point at which it is assumed that a receptor (either actual or potential) can currently or in the future come in contact with the CoC.

Exposure points may include, but are not limited to:

- private and public water supply wells;
- irrigation wells;
- surface water bodies (e.g., lakes, streams, rivers);
- sensitive habitats (e.g., wetlands, fisheries, shellfish areas); and
- underground utilities, building basements, etc.

All current or future exposure pathways should be considered for each CoC.

An exposure pathway is the course that the CoC takes from the source to a receptor. To determine if the pathway is complete, the Tier 2 Risk Evaluation must provide sufficient information to identify the source and the transport mechanisms to the exposure point. For example, if a CoC reaches an underground utility, the construction material (e.g., PVC, ductile iron, etc.) of the underground utility and the types of seals (e.g., glue, neoprene, etc.) at the pipe couplings should be identified and used to determine if a potential exists for the CoC to enter those lines resulting in an exposure to the receptor. For a given medium and exposure route, if a risk does not exist for a selected pathway then the exposure point should not be further evaluated.

For the ground water ingestion pathway, the exposure point must be established based on current and reasonably anticipated future use of the ground water. Table 5 gives examples of exposure points for various possible situations. Please refer to STEP 3 (pages 9 & 10) Site Conceptual Exposure Model for details on how to identify if the adjacent property is a possible exposure point.

2) Establish Point(s) of Compliance

A point of compliance is a location selected between the source area (area of maximum concentrations) and the exposure point where the concentration of each CoC must be at or below the Compliance Point Concentration (CPC). Typically the CPC is between the SSTL at the source area and RBSL applied at the exposure point.

Points of compliance should be established down gradient of the source area but hydraulically up gradient of an exposure point. At least one point of compliance must be located between the source area and the exposure point for each completed pathway, with a minimum of one year travel time for the CoC from the point of compliance to the exposure point. Additional point(s) of compliance are necessary where complex hydrogeological conditions exist that may control CoC migration.

When establishing point(s) of compliance the following factors must be considered:

- locations of current receptors;
- locations of potential receptor(s);
- current and projected land and resource usage; and
- velocity of the CoC in soil, ground water or air.

Table 5
Choice of Exposure Points

Site status	Down gradient offsite property status	Exposure Point should be located	Figure
Actual or potential source of water	Source of water or not	At source area	**2a**
Within the radius of influence of a pumping well	Source of water or not	At the edge of the well's radius of influence	**2b**
No Exposure Point on the property	Off site is a source of water	Closest offsite property boundary	**2c**
No Exposure Point on the property	Offsite is not a source of water	Hydraulically up gradient of a potential receptor	**2d**

Figure 2a

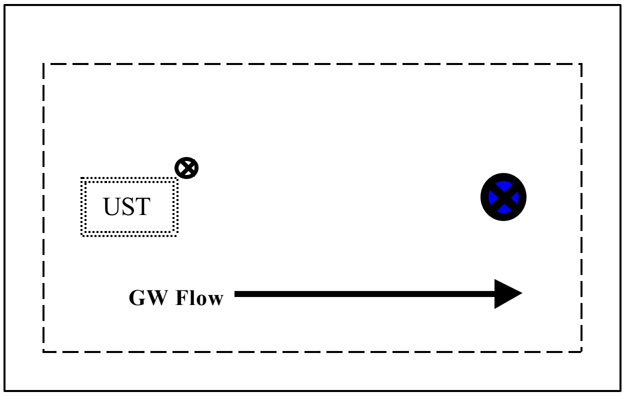


Figure 2b

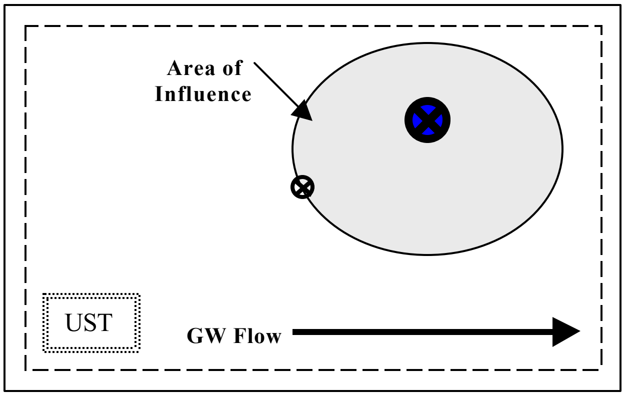


Figure 2c

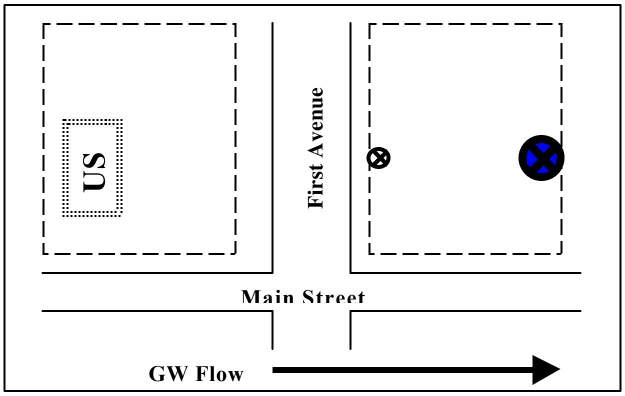
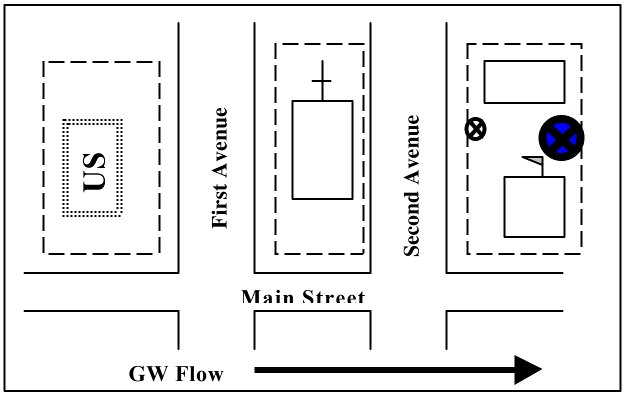


Figure 2d



⊗ **Exposure Point** ● **Potable Water Well** ------------ **Property Boundary**

3) Establish the SSTL

Site-specific target levels should be established for each CoC and each particular pathway identified in the site conceptual model based on the spatial and temporal (both measured and predicted) attenuation of the concentration of each CoC above the RBSL. All possible scenarios must be evaluated during this process utilizing simple fate and transport models. Input data can be limited to site-specific data attainable through standard industry practices. All assumptions must be listed and fully explained.

The following steps should be followed to complete the Tier 2 evaluation:

a) For the soil leaching to ground water pathway, the SSTL for soil can be calculated using the leachability model provided in Appendix C. Following the method described below, it may be appropriate to first calculate the SSTL for the ground water pathway before using the leachability model. The soil SSTL must be protective of the estimated SSTL for ground water.

b) For the ground water ingestion pathway, there are two methods that can be used to estimate the reduction of CoC in the saturated zone: i) using empirical data and ii) models implemented with site-specific data.

> i) In a case where the CoC plume is shown to be stable or shrinking (by monitoring data), empirical data can be used to approximate the Concentration Reduction Factor (CRF) of the CoC in the relevant medium from the source to exposure point. For example, if the concentration of benzene in source area is 100 micrograms per liter (µg/L) and the actual measured non-zero concentration in the most down gradient monitoring well is 10 micrograms per liter (µg/L), then benzene has been documented to be reduced by a factor of 10 (i.e., the CRF is 10). The SSTL = RBSL X CRF. Since the ground-water RBSL for benzene is 5 µg/L to be applied at the exposure point, the SSTL for ground water to be met at the source area is (5 µg/L * 10) =50 µg/L.
>
> ii) Fate and transport models can also be used to calculate the SSTLs. SSTLs are typically calculated by calibrating the model using actual measured site-specific data and then, increasing or decreasing the concentration in the source area until the concentration at the receptor will not exceed the RBSL. Appendix D describes the Domenico's model. For sites with site-specific conditions that may warrant a more complex analysis, it may be appropriate to utilize computer models such as Bioscreen, Solute, AT123D, Bioplume II, and other applicable models to calculate the SSTLs. All assumptions made must be valid and the input parameters, along with explanation for their choice, must be provided with the modeling results.

For other chemicals:

c) In a Tier 2 evaluation, SSTLs for the dermal contact, soil and ground water ingestion and vapor inhalation pathways shall be based on a carcinogenic risk limit of 10^{-6} and a hazard index of 1 for non-carcinogens to be applied at the exposure point. Each chemical is evaluated separately for each exposure route as SCRBCA does not consider the additive effect of risk from different chemicals and different routes of exposure. The state toxicologist will be consulted as necessary to provide recommended exposure limits.

STEP 7 - TIER 2 ACTION

Once the Tier 2 evaluation is completed, three decision options are available for consideration based on the CoC concentrations:

1) Monitored Natural Attenuation Action

If the representative concentrations (see STEP 3) of the CoCs are below the SSTLs, further CoC delineation is not necessary. A CAP proposing a short-term (e.g., 18 months or less) monitoring program to verify natural attenuation should be submitted. The Corrective Action Guidance Document describes the details of demonstrating natural attenuation.

2) Active Corrective Action

If the concentration of the CoCs are above the SSTLs and Tier III assessment is not considered an appropriate option, corrective action to achieve Tier 2 SSTLs should be recommended. Free-phase product must be removed to the extent practicable pursuant to R.61-92, Section 280.64.

3) Tier III Assessment

If the concentrations of the CoCs are above the SSTLs, Tier 3 evaluation is warranted under the following conditions:

- If the SSTLs developed under Tier 3 evaluation are anticipated to be significantly different than the Tier 2 SSTLs (i.e., concentrations of CoC exceed the SSTLs but it is predicted that the use of site-specific biodegradation data will allow different site-specific cleanup goals to be determined);

- If the cost of remedial action to Tier 2 SSTL will likely be greater than Tier 3 evaluation (data collection, analysis, review, etc.) and subsequent remedial action; and

- The approach used to derive the Tier 2 goals is not appropriate for conditions at the site.

STEP 8 - TIER III ASSESSMENT

In a Tier III, SSTLs for the source area and the point(s) of compliance are developed on the basis of more sophisticated statistical and CoC fate and transport analyses using site-specific input parameters for appropriate exposure scenarios. Any additional information required for site-specific modeling efforts should be proposed in a Tier II Assessment (former RA) Plan.

STEP 9 - TIER 3 EVALUATION

The Tier 3 evaluation involves the use of more sophisticated mathematical models than those used in Tier 2 (e.g., computer analytical models) or numerical ground-water modeling codes that predict time-dependent dissolved CoC transport under conditions of spatially varying permeability fields to predict exposure point(s) concentrations and to re-calculate SSTLs based on more site-specific data. Monte Carlo models, which allow a range of fate and transport scenarios to be calculated, may also be appropriate. Less conservative site-specific exposure factors can be used in calculations for commercial and industrial sites if pre-approved by the Department. All assumptions, methods and models must be submitted for pre-approval.

STEP 10 - TIER 3 ACTION

Once the Tier 3 evaluation is completed, two decision options are available for consideration based on the CoC concentrations:

1) Monitored Natural Attenuation (MNA) Action

If the concentrations of the CoCs are below the SSTLs, further CoC delineation is not necessary. A CAP proposing a short-term monitoring program to verify natural attenuation should be submitted. The Corrective Action Guidance Document describes the details of demonstrating natural attenuation.

2) Active Corrective Action

If the concentrations of the CoCs are above the SSTLs, an active cleanup to achieve Tier 3 SSTLs should be recommended.

STEP 11 - CORRECTIVE ACTION (ACTIVE OR MNA)

The selected active corrective action methodology must be designed to achieve SSTLs for each CoC. An appropriate monitoring program will be required to ensure that the target goals continue to be met. Once the SSTL for every CoC is achieved, a verification monitoring program to demonstrate natural attenuation should be implemented. Please refer to the Corrective Action Guidance Document for details. Departmental approvals and/or permits are required for all CAPs, air and water discharges, underground injection, etc. Detailed design specifications must be developed for installation and operation of above ground remediation systems. All planned corrective actions, whether active or MNA, will be placed on public notice as required by the SCUSTCR (R.61-92, 280.66) to allow potentially affected parties to participate in the corrective action decision-making process.

STEP 12 - VERIFICATION MONITORING FOR MONITORED NATURAL ATTENUATION

During or following a corrective action, a compliance monitoring program may be required to ensure that the target goals continue to be met and the assumptions and predictions used in Tier 2 and 3 are verified. In order to reach these goals, appropriate monitoring parameters (organic and inorganic, as necessary), frequency of monitoring, and monitoring methods will be established based on site-specific requirements. Once monitoring data support the conclusion that the contaminant plume has reached equilibrium or is not moving at a significant rate; that concentrations of CoCs are not increasing; that no unacceptable to risk to human health, safety, or the environment exists; and that the CoCs will naturally attenuate over time, no further action under SCRBCA is necessary.

STEP 13 - NO FURTHER ACTION DECISIONS

No further action (NFA) decisions will be issued by the Department for underground storage tank releases where additional site rehabilitation actions are not required. An NFA is issued where each CoC for soil, vapor or ground water has decreased to the RBSL.

A Conditional No Further Action (CNFA) may be issued upon the Department's concurrence that the petroleum CoC concentrations are less than SSTLs but still greater than the RBSLs. Such decisions can be reached only when verification monitoring documents that natural attenuation is taking place, and that no risk to human health or environment will result. For example, if concentrations of CoCs are present but below SSTLs in the ground water in areas where human consumption is prevented by local ordinances, then no further actions are necessary and a CNFA may be issued. Again, this decision is based on the demonstration that the release does not pose a risk to human health or the environment. The Department's CNFA decision will be issued in writing to the owner/operator and all assumptions and conditions will be outlined (e.g., the ground water should not be used for consumption). A registry of releases will be maintained in the SCDHEC Freedom of Information office to assist the public and document the status of release(s). This registry will identify the location of the UST release, the affected property (or properties), and the assumptions and conditions of the CNFA. If the Owner/Operator provides information to support that the concentrations associated with the release are at levels below risk-based screening levels for all the CoCs of concern at a facility where a CNFA has been issued, then the release will be given a NFA.

APPENDIX A
SCRBCA SITE PRIORITY CLASSIFICATION SYSTEM

SCRBCA Site Priority Classification System

1. Sites are placed in Classification 1 if:

   - an emergency situation exists
   - a fire or explosion hazard exists
   - vapors or free product exists in a structure or utility
   - concentrations of CoC have been detected in a potable water supply or surface water supply intake
   - free product exists on surface water
   - CoC exist in surface water

2. Sites are placed in Classification 2 if:

   Classification 2a:

   - a significant near term (0 to 1 year) threat to human health, safety, or sensitive environmental receptors exists
   - potable supply wells or surface water supply intakes are located < 1 year ground water travel distance downgradient of the source area

   Classification 2b:

   - free product exists in a monitoring well at a measured thickness > 1 foot
   - potable supply wells or surface water supply intakes are located < 1000 feet downgradient of the source area (where ground-water velocity data is not available).

3. Sites are placed in Classification 3 if:

   Classification 3a:

   - a short-term (1 to 2 years) threat to human health, safety, or sensitive environmental receptors exists
   - potable supply wells or surface water supply intakes are located > 1 year and < 2 years ground-water travel distance down-gradient of the source area
   - sensitive habitats or surface water exist < 1 year ground-water travel distance downgradient of the source area and the ground water discharges to the sensitive habitat or surface water

Classification 3b:

- free product exists in a monitoring well at a measured thickness > 0.01 foot
- concentrations of CoC above the RBSL have been detected in a non-potable water supply well
- hydrocarbon-containing surface soil (< 3 feet below grade) exists in areas that are not paved
- sensitive habitats or surface water used for contact recreation exist < 500 feet downgradient of the source area (where ground-water velocity and discharge location data are not available).
- the site is located in a sensitive hydrogeologic setting, determined based on the presence of fractured or carbonate bedrock hydraulically connected to the impacted aquifer
- ground water is encountered < 15 feet below grade and the site geology is predominantly sand or gravel

4. Sites are placed in Classification 4 if:

Classification 4a:

- a long term (> 2 years) threat to human health, safety, or sensitive environmental receptors exists
- potable supply wells or surface water supply intakes are located > 2 years and < 5 years ground-water travel distance downgradient of the source area
- non-potable supply wells are located < 1 year ground water travel distance downgradient of the source area

Classification 4b:

- free product exists as a sheen in any monitoring wells
- non-potable supply wells are located < 1000 feet downgradient of the source area (where ground-water velocity data is not available)
- the ground water is encountered < 15 feet and the site geology is predominantly silt or clay

5. Sites are placed in Classification 5 if:

- there is no demonstrable threat, but additional data are needed to show that there are no unacceptable risks posed by the site
- assessment data for the site indicate concentrations in some samples are above the RBSL or SSTL, as appropriate, and further assessment is needed
- assessment data for the site indicate concentrations in samples are below the RBSL or SSTL, as appropriate, but the samples are determined not to be representative; therefore, further assessment is needed

APPENDIX B
RISK BASED SCREENING LEVELS LOOK-UP TABLES

Risk Based Screening Level Look-Up Tables

The RBSLs for CoC in ground water are based upon the maximum contaminant levels (MCL) or health advisory concentrations and Health Advisory concentrations, published in the Environmental Protection Agency's Drinking Water Regulations.

Table B1

RBSL'S for Ground Water

Chemical of Concern	Concentration
Benzene	5 µg/L
Toluene	1,000 µg/L
Ethylbenzene	700 µg/L
Xylenes	10,000 µg/L
Total PAHs ★	25 µg/L
MTBE	40 µg/L
Naphthalene (includes methyl naphthalenes)	25 µg/L
EDB ●	0.05 µg/L
Lead ●	15 µg/L
Arsenic **	50 µg/L
Barium **	2,000 µg/L
Cadmium **	5 µg/L
Total Chromium **	100 µg/L
Mercury **	2 µg/L
Selenium **	50 µg/L
Silver **	5 µg/L

★ In calculating SSTLs for individual PAHs (Benzo(a)anthracene, Benzo(b)flouranthene, Benzo(k)flouranthene, Chrysene, and Dibenz(a,h)anthracene), please use an RBSL of 10 µg/L for each CoC.

● UST system was in operation prior to 1991.

** For waste oil UST releases only.

A recent study by the University of South Carolina (Bene & Gribb, 2000) has concluded that the soil leachability model, as presented in the SC RBCA (1998) may not be applicable when separation distance is less than 8 feet. It has also been determined, from previous studies by the University of South Carolina (Gribb, 1998 and Gribb & Bene, 1999) and the field data available with SCDHEC, that in the case of sand-rich soil, the RBSLs did not significantly change at various separation distances (Table B3 in SCRBCA, 1998). The Chemicals of Concern from petroleum releases readily leach to groundwater in sand-rich soils and continue to be present despite large separation distances. Therefore in the case of sand-rich soil, only one set of RBSLs shall be utilized for all separation distances. These values have been calculated based on the groundwater RBSLs and are shown in the Table B2 below.

In the case of clay-rich soil, the RBSLs of the CoCs were recalculated using a more conservative DAF value of 1. For separation distances less than 10 feet RBSLs were recalculated based on the ground water RBSLs. The input parameters used for the leachability calculations are shown in Table B3 and the RBSLs are show in Table B4 below.

Table B2

RBSLs for Sandy Soil determined based on groundwater RBSLs (Table B1).

Chemical of Concern	RBSL (mg/Kg) (for all separation distances)
Benzene	0.007
Toluene	1.450
Ethylbenzene	1.150
Xylenes	14.500
Naphthalenes	0.036
Benzo(a)anthracene	0.066 •
Benzo(b)flouranthene	0.066 •
Benzo(k)flouranthene	0.066 •
Chrysene	0.066 •
Dibenz(a,h)anthracene	0.066 •

- Limits are increased to levels above the calculated values to reasonably attainable reporting limits.

Table B3

Input parameters used to derive RBSLs for the clay-rich (40% clay and 20% sand) soil.

Parameter	Assumed Value
TPH – total petroleum hydrocarbons	1,000 mg/Kg
FOC – total organic carbon	100 mg/Kg
H_w - average annual recharge rate	25 cm/yr
$t_{1/2}$ - biodegradation half-life period	see Table C2
K_{oc} - organic/water partitioning coefficient	see Table C2
N - porosity	0.52
W_r - residual water content	0.08
B_d - bulk density	1.30 g/cc
H_f - wetting front suction head	-65 cm
K - hydraulic conductivity	1.8E-5 cm/s
DAF	1

Using the above conservative parameters as input to the Leachability model (Appendix C), the RBSL table for Clay-rich Soil is generated as shown in Table B4.

Table B4

RBSLs for Clay-rich Soil (mg/kg)

Separation Distance → **↓ Chemical of Concern**	**<10 ft**	**10-15 ft**	**15-20 ft**	**20-25 ft**	**25-30 ft**	**>30 ft**
Benzene	**0.003**	**0.008**	**0.037**	**0.187**	**1.010**	**5.665**
Toluene	**0.627**	**1.167**	**3.630**	**12.085**	**41.885**	**149.125**
Ethylbenzene	**1.551**	**6.168**	**76.950**	**1114.5**	**-**	**-**
Xylenes	**13.010**	**22.495**	**61.250**	**176.800**	**529.000**	**-**
Naphthalenes (includes methyl naphthalenes)	**0.047**	**0.069**	**0.139**	**0.292**	**0.625**	**1.350**
Benzo(a)anthracene	**0.066***	**-**	**-**	**-**	**-**	**-**
Benzo(b)flouranthene	**0.066***	**7439.0**	**-**	**-**	**-**	**-**
Benzo(k)flouranthene	**0.066***	**-**	**-**	**-**	**-**	**-**
Chrysene	**0.066***	**13.099**	**59.800**	**298.550**	**1573.000**	**-**
Dibenz(a,h)anthracene	**0.066***	**-**	**-**	**-**	**-**	**-**

Note: Separation Distance is measured from the depth of the worst case soil sample to the top of the water table.

*** Limits are increased to levels above the calculated values to reasonably attainable laboratory reporting limits.**

- Indicates that the values are above saturation levels

All values in Tables B5 and B6 were obtained from the EPA Region III Risk-Based Concentration Table (April 2000).

Table B5

RBSLs for Inhalation of vapors

Chemical of Concern	RBSL (µg/m^3)
Benzene	0.22
Toluene	420
Ethylbenzene	1,100
Xylene	7,300
Methyl Tert-Butyl Ether	3,100

Note: RBSLs for the PAHs are not of concern because of their low volatility.

Table B6

RBSLs for Ingestion or Dermal Contact with Surficial Soil

Chemical of Concern	Residential (mg/kg)	Industrial (mg/kg)
Benzene	12	100
Toluene	16,000	410,000
Ethylbenzene	7,800	200,000
Xylene	160,000	4,100,000
Methyl Tert-Butyl Ether	390	10,000
Naphthalenes	3,100	41,000
Benzo(a)anthracene	0.88	3.9
Benzo(b)fluoranthene	0.88	3.9
Benzo(k)fluoranthene	8.8	39
Chrysene	88	390
Dibenzo(a,h)anthracene	0.088	0.39

APPENDIX C
SOIL LEACHABILITY MODEL

Leachability Model for Petroleum Contaminated Soils

The following approach is provided to determine whether leachates from petroleum contaminated soils will migrate to ground water and to determine Site Specific Target Levels (SSTLs) for cleanup of impacted soil. If soil concentrations are above the Risk Based Screening Levels (RBSLs) the soil leachability model can be used to determine if soil remediation is necessary. The model utilizes a series of mathematical equations that quantify contaminant partitioning, transport, degradation, and dilution processes. **Please note that the Leachability Model should be used only when the separation distance is more than 8 feet.**

Data Acquisition

Proper application of this model requires complete delineation of the horizontal and vertical extent of impacted soil and the analysis of representative soil samples. The Tier I Assessment (former Standard Limited Assessment) guidance document provides guidelines for the number and locations of soil samples to be collected around the tanks, lines, and dispensers at a typical underground storage tank facility. If the horizontal and vertical extent of impacted soil has not been completely delineated during the Tier I assessment, additional samples should be collected during the Tier II Assessment (former Rapid Assessment). A complete soil assessment should include:

A. Installation of soil borings as explained below. No boring should be advanced below the water table.

   1. Soil borings shall be advanced to the ground water * in the area occupied by the former or existing underground storage tanks, piping, and dispensers.

   2. Soil borings shall be advanced to the ground water * adjacent to impacted borings to complete the full delineation.

   3. Background Soil Boring : One soil boring shall be installed to a depth of 10 feet or to the ground water table, whichever is shallower, and at least thirty feet away from any USTs, product lines, dispensers, and other potential sources of CoC. If the site is too small to allow a separation of thirty feet, this soil boring shall be installed as far away from all USTs, product lines, dispensers, and other potential sources of CoC as possible. The soil sample must be collected from below the A-horizon unless a shallow water table precludes this.

   * If the field screening results indicate that petroleum impact does not extend to the water table, the boring may be terminated after three consecutive clean split-spoon samples at five-foot intervals for the Tier I and Tier II Assessments or a boring to a depth of 50 feet for an Initial Ground Water Assessment. A soil sample shall be collected from the termination depth of that boring to verify the vertical extent of impacted soil. A second sample shall be collected from the depth interval that exhibits the highest concentration of impact. Both samples shall be analyzed by a South Carolina certified laboratory for appropriate CoC.

B. The lithology for each soil sample collected during boring installation shall be appropriately described. Samples shall be screened for organic vapors utilizing properly calibrated instruments. For other less volatile chemicals such as diesel or kerosene, alternative screening methods (e.g., field GC, immunoassay, etc.) can be used.

C. The soil sample from each boring around the USTs, piping, and dispensers shall be submitted to a Department certified laboratory for analyses as follows :

1. The sample (from each boring) with the highest organic vapor measurement shall be submitted to the laboratory for analysis. If the organic vapor measurements for all samples in a boring are within ten percent of each other, the sample from the greatest depth above the water table shall be submitted for analysis.

2. The samples (one from each soil boring) submitted to the laboratory shall be analyzed for the appropriate CoC using the methods as listed below.

<u>Table C1</u>

Reporting limits and suggested analytical methods for soils

Product	CoC	Suggested Method	Method Detection Limits
Gasoline, Diesel, Fuel Oil, Kerosene	BTEX Total Naphthalenes Other PAHs	8260B• 8260B• 8270C*	1 µg/Kg 5 µg/Kg 66 µg/Kg
Leaded Gasoline ν	Lead	6010B or 7421	5 µg/Kg
Waste or Used Oil	Metals TPH	AA or ICP* 9071*	10 µg/Kg 10 mg/Kg

BTEX - Benzene, Toluene, Ethylbenzene, Xylenes

Others PAH - Benzo(a)anthracene, Benzo(b)flouranthene, Benzo(k)flouranthene, Chrysene, Dibenz(a,h)anthracene

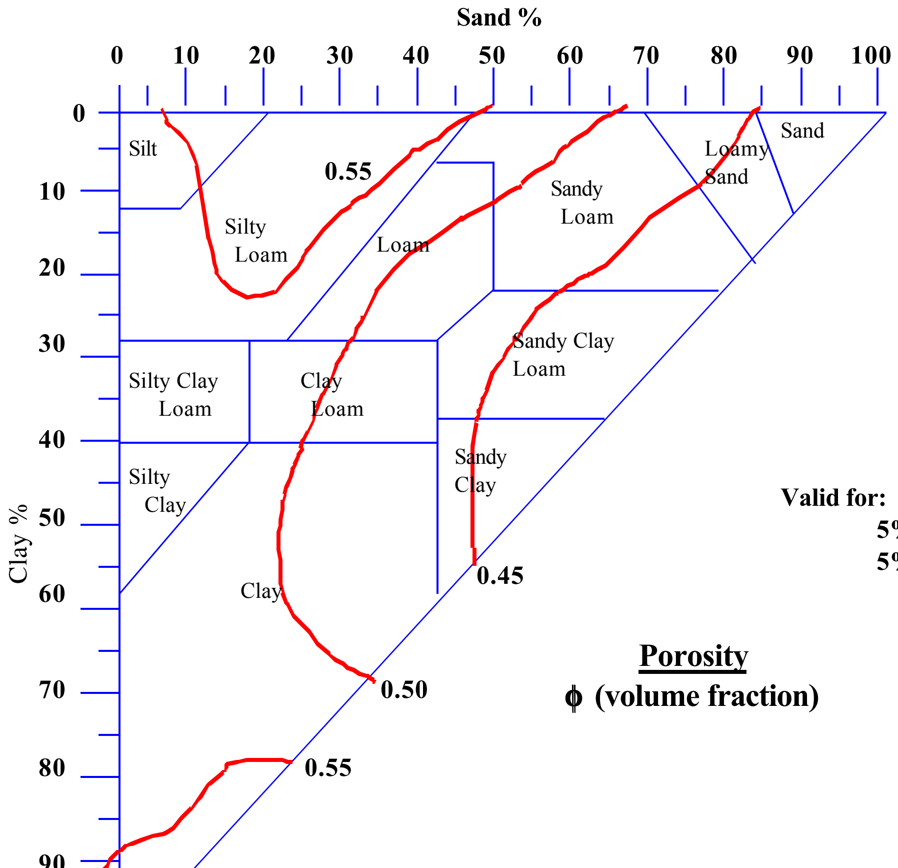
Metals - Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver

AA - Atomic Absorption
ICP - Inductively Coupled Plasma

• UST Program does not allow any equivalent methods for 8260B method.

* An equivalent method that can achieve the same method detection limits may be substituted. Please refer to the analytical methodology guidance document (SCDHEC, 2000)

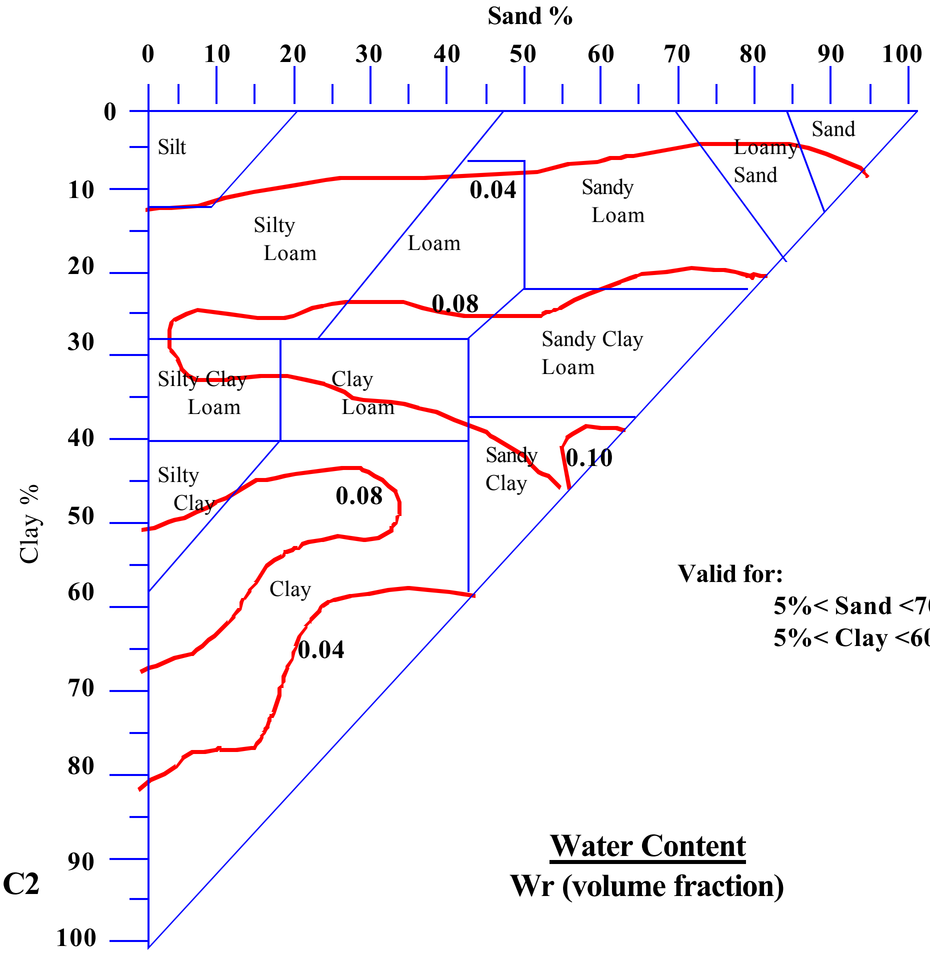
ν If tanks were in operation prior to 1991.



Valid for:
5%< Sand <70%
5%< Clay <60%

Porosity
ϕ (volume fraction)

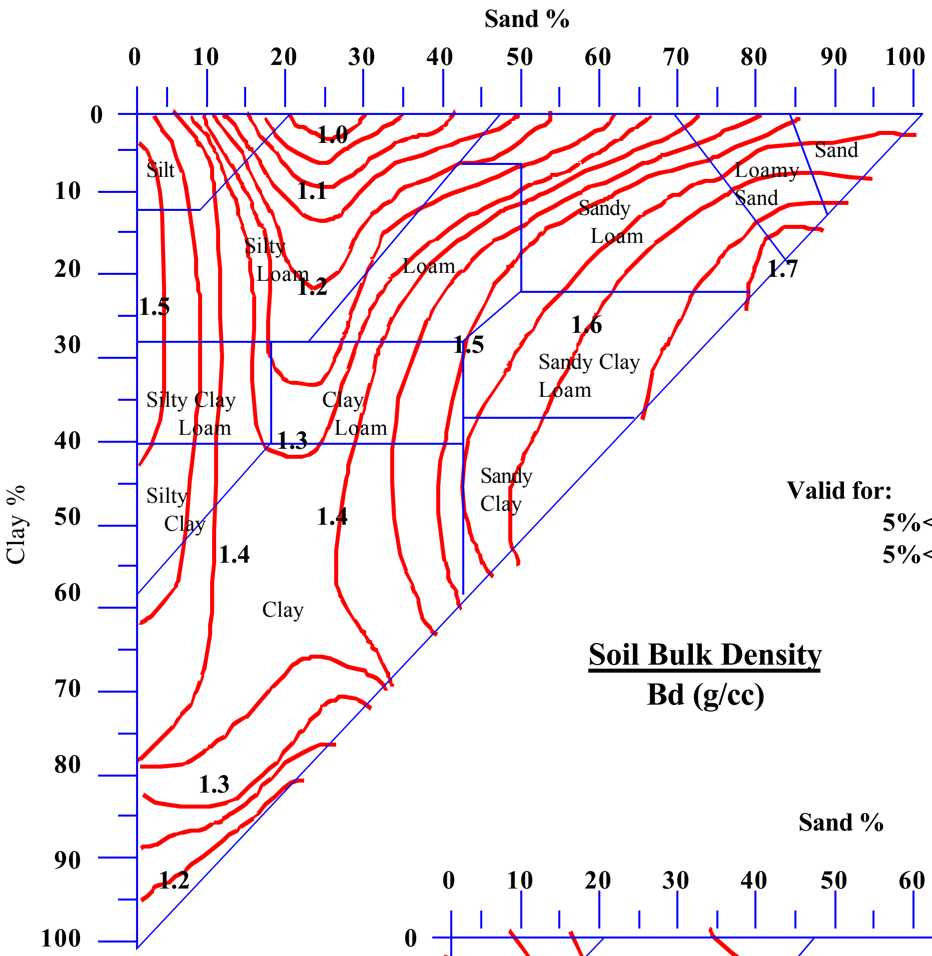
Figure C1



Valid for:
5%< Sand <70%
5%< Clay <60%

Water Content
Wr (volume fraction)

Figure C2



Valid for:

5%< Sand <70%

5%< Clay <60%

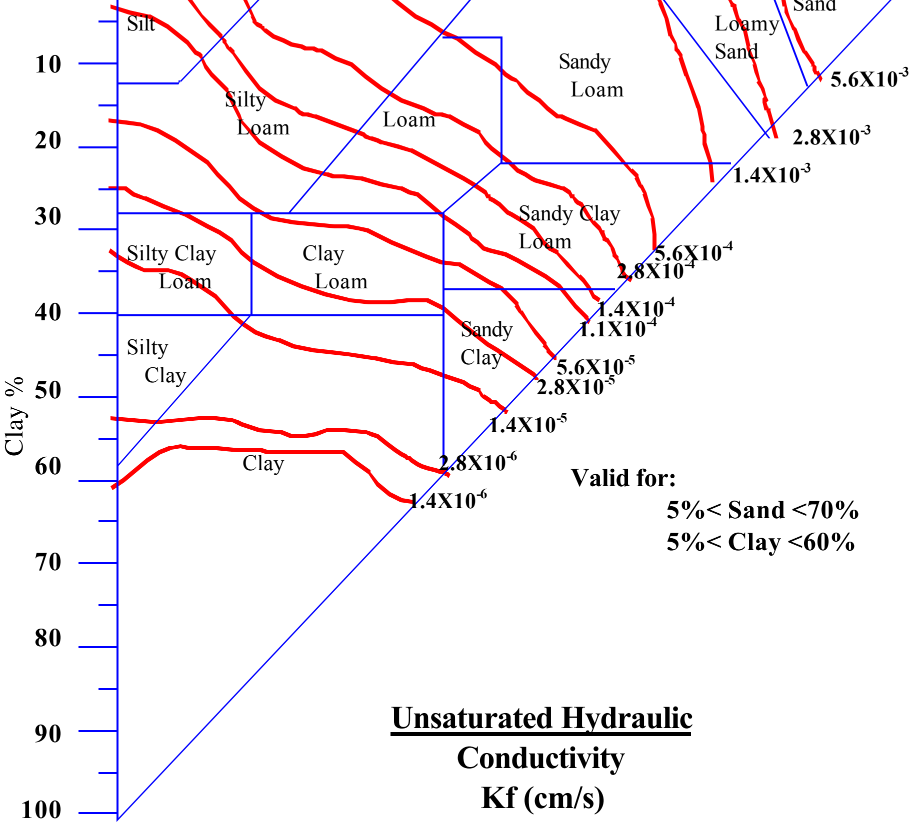
Soil Bulk Density

Bd (g/cc)

Figure C3

Sand %

0 10 20 30 40 50 60 70 80 90 100



Valid for:

5%< Sand <70%

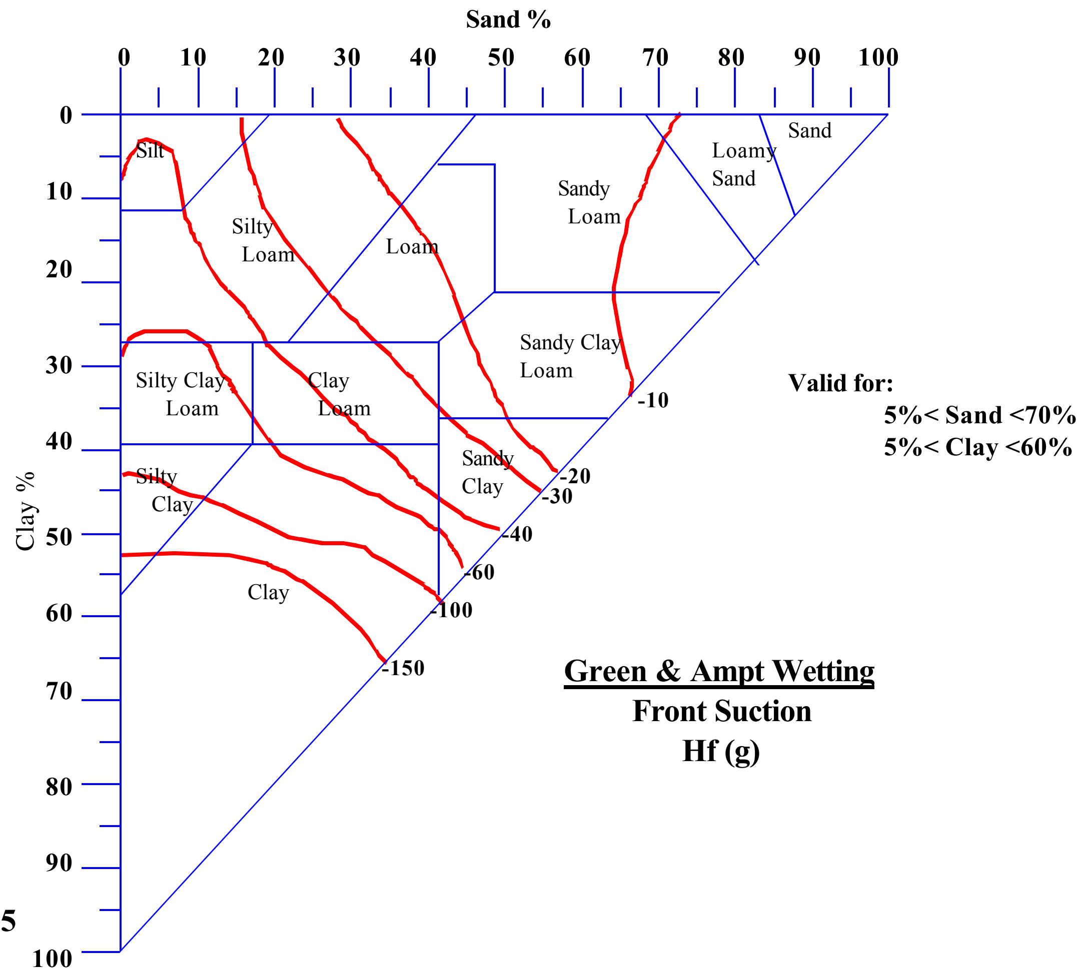
5%< Clay <60%

Unsaturated Hydraulic

Conductivity

Kf (cm/s)

Figure C4



Valid for:

5%< Sand <70%

5%< Clay <60%

Green & Ampt Wetting

Front Suction

Hf (g)

Figure C5

3. In addition to the analyses listed above, soil samples shall be collected from the soil boring with the highest organic vapor measurement as follows :

   a. One soil sample shall be collected from the terminus of the boring (above the ground water table). This sample shall be submitted to a laboratory for a grain size and hydrometer analysis to determine the sand, silt, and clay fractions at 0.074 millimeters (#200 screen) and 0.004 millimeters respectively.

   b. One soil sample shall be collected from the stratigraphic level exhibiting the highest organic vapor measurement (above the ground water table). This sample shall be analyzed for Total Petroleum Hydrocarbons (**TPH**) using EPA Method 3550B/8015B.

4. The soil sample collected from the background soil boring shall be analyzed for total organic carbon ($\mathbf{f}_{oc}$) utilizing EPA Method 415.1 or an EPA approved equivalent. The presence of calcareous soil shall be noted for possible analytical interferences. The presence of stained soil, peat beds, unusually high organic content, or other unusual conditions shall also be noted.

All soil borings must be properly abandoned pursuant to the South Carolina Well Standards and Regulations R.61-71.

SOIL LEACHABILITY MODEL INPUT PARAMETERS

The following input parameters are needed to utilize the equations. Forms for site specific input parameters and calculated results are provided which can be used to summarize the pertinent soil leachability input data, results and conclusions.

The following equations are valid for:

5% < Sand < 70%
5% < Clay < 60%

For sediments that are outside these ranges, the nearest maximum or minimum values should be used.

B_d	**Bulk density** is defined as the weight of oven dry soil divided by the total volume of soils (solids +pores). Based on the grain size distribution, Bd can be estimated from Figure C3.
C_{rbsl}	**Risk based Screening Level** (mg/L) for CoC in ground water. If appropriate, this can be substituted by the site specific target level for the CoC in ground water.
C_s	**Concentration of CoC** (mg/Kg) in soil.
C_{sstl}	**Site Specific Target Level** (mg/Kg) for chemical of concern in soil.
f_{oc}	The **natural organic content** (mg/Kg) **of uncontaminated background soil**, typically determined by analysis of total organic carbon (TOC) by EPA Method 415.1. Naturally occurring TOC values in uncontaminated "B" and "C" horizon soils usually range from 100 to 1000 mg/Kg.
H'	The **Henry's Law Constant** (mg/l)/(mg/l) relates the partial pressure of a gas and its corresponding solubility in water at a given temperature. Some averaged values for typical petroleum constituents are provided in Table C2.
H_f	The **wetting front suction head** (cm) is the pressure head at the wetting front as it advances downward. Critical pressure head is <u>always negative</u>. Based on the grain size distribution, H_f can be estimated from Figure C5.
H_w	**Average annual recharge** (precipitation minus evapotranspiration and runoff). Assume 25 centimeters unless additional information is available.
K_f	**Soil hydraulic conductivity** (cm/s). Based on the grain size distribution, the field saturated hydraulic conductivity in the vadose zone can be estimated from Figure C4.
K_{oc}	The **soil/water partitioning coefficient** (ml/g) is compound specific and provides an indication of the tendency of CoC to partition between particles containing organic carbon and water. Some averaged values for typical petroleum constituents are provided in Table C2. Please note that the values in Table C2 are most applicable for soils containing an f_{oc} **value** $\geq$ **1%**.

L The **separation distance** (cm) between the depth of the soil sample exhibiting the highest concentration of CoC and the measured water table. For example, if the soil sample with the highest concentration of CoC occurred at 10 feet below land surface (bls) and ground water was encountered at 20 feet bls, then L = 10 feet = 304.8 cm.

N **Porosity** (decimal %) is the percentage of the rock or soil that is void of material. Based on the grain size distribution, the porosity can be estimated from Figure C1.

W_r **Residual water content** (decimal %) is the weight of the water remaining in the soil divided by the total weight of the soil sample. Based on the grain size distribution, the residual water content can be estimated from Figure C2.

$t_{1/2}$ The **biodegradation half-life period** (days) of CoC. This is compound specific. Some conservative values for typical petroleum constituents in vadose zone under anaerobic conditions are provided in Table C2.

Table C2

Chemical Specific Soil Data

CoC	**K_{oc}** * (ml/g)	**H'** (mg/l)/(mg/l)*	**$t_{1/2}$** ** (days)
Benzene	81	0.226	16
Toluene	133	0.301	22
Ethylbenzene	176	0.280	10
Xylene	639	0.278	28
Naphthalenes	1543	0.002	48
Benzo(a)anthracene	1,380,384	0.0002	679
Benzo(b)fluoranthene	549,541	0.0005	610
Benzo(k)fluoranthene	4,365,158	0.043	2,139
Chrysene	245,471	3.02 x 0^{-18}	993
Dibenz(a,h)anthracene	1,659,587	3.05 x 10^{-7}	942

* From Montgomery. J.H. et.al., 1991, Groundwater Chemicals Desk Reference. Lewis Publishers.

** From Howard, P.H. et.al., 1991, Environmental Degradation Rates, Lewis Publishers.

Leachability model calculations consist of the following equation sets. Each set consists of several steps that should be used in calculating the different intermediate parameters.

Equation Set I

Determination of total organic carbon and air filled porosity

Step 1

Total organic carbon content (**f_{cs}**) (unitless) of the soil is calculated using the following equation:

$$\mathbf{f_{cs}} = \left(\mathbf{f_{oc}} + \frac{\mathbf{TPH}}{\mathbf{1.724}} \right) \left(\mathbf{1x10^{-6}} \right)$$

where,

f_{oc}	is the natural organic carbon content (mg/Kg) of uncontaminated soil (see data acquisition section).
TPH	is the Total Petroleum Hydrocarbon (mg/Kg) by EPA Method 3550B/8015B.
1.724	is the conversion from organic matter to organic carbon fraction.
1×10^{-6}	is the conversion from mg/Kg to decimal %.

Step 2

The air filled porosity (**f**) (decimal %) can be approximated using the following equation:

$$\mathbf{f = \phi - W_r}$$

where,

ϕ is the porosity (decimal %) from Figure C1.
W_r is the residual water content (decimal %) from Figure C2.

Equation Set II

Determination of the velocity of the soil pore water (V_w)

Step 1

The infiltration rate of water through soil under constant head conditions (Green & Ampt equation as discussed in Bouwer, 1978) is determined. The result provides the time (**t**) it should take water to percolate through the vadose zone soil (from the depth of the worst case soil sample to the water table at the site).

$$\mathbf{t} = \left(\frac{\mathbf{f}}{\mathbf{K_f}} \right) * \left[\mathbf{L} - \left(\left\{ \mathbf{H_w - H_f} \right\} * \left\{ \mathbf{ln} \frac{\mathbf{H_w + L - H_f}}{\left(\mathbf{H_w - H_f} \right)} \right\} \right) \right]$$

where

f is the air filled porosity of soil (decimal %) calculated in Step 2 of Equation Set I.
$\mathbf{K_f}$ is the field saturated hydraulic conductivity (cm/s) which can be estimated from Figure C4.
L is the distance (cm) from the depth of the worst case soil sample to the water table.
$\mathbf{H_w}$ is the average annual recharge (cm), default value = 25 cm.
$\mathbf{H_f}$ is the Wetting front suction head (cm) which can be estimated from Figure C5.

Step 2

Taking the above calculated value for time (t) in seconds the velocity of the water (V_w) in feet per year is calculated using the following equation:

$$\mathbf{V_w = \left(\frac{L}{30.48}\right) * \left(\frac{3.15 * 10^7}{t}\right)}$$

where,

L is the distance (cm) from the depth of the worst case soil sample to the water table.
t is the time (s) required for water to travel distance L, calculated in Step 2.

<u>Equation Set III</u>

<u>Determination of the organic retardation effect (V_c) on the contaminant</u>

Step 1

The soil/water distribution coefficient (K_d) (ml/g) for uncontaminated soil is calculated using the following equation:

$$\mathbf{K_d = K_{oc} * f_{oc} * (1 \times 10^{-6})}$$

where,

$\mathbf{K_{oc}}$ is the soil organic/water partitioning coefficient (ml/g) from Table C2.
$\mathbf{f_{oc}}$ is the natural organic carbon content (mg/Kg) of uncontaminated soil (see data acquisition section).
$\mathbf{1 \times 10^{-6}}$ is the conversion from mg/Kg to decimal %.

Step 2

The retardation effect of natural soil organic matter on CoC migration is calculated using the following equation:

$$\mathbf{V_c = \frac{V_w}{1 + \left(\frac{Bd * Kd}{Ö}\right)}}$$

where

$\mathbf{V_c}$ is the CoC percolation rate (ft/yr)
$\mathbf{V_w}$ is the water percolation rate (ft/yr) from Step 3 of Equation Set II.
$\mathbf{B_d}$ is the bulk density of soil (g/cc) from Figure C3.
$\mathbf{K_d}$ is the soil/water distribution coefficient (ml/g) calculated in Step 1.
ϕ is the porosity (decimal %) from Figure C1.

Equation Set IV

Determination of biodegradation rates and final CoC concentration ($\mathbf{C_p}$) in the soil pore water necessary to protect ground water

Step 1

The following equation is used to calculate the time (days) required for the CoC to reach ground water using

$$\mathbf{T_c = \frac{365 * L}{30.48 * V_c}}$$

where,

L is the distance (cm) from the depth of the worst case soil sample to the water table.
$\mathbf{V_c}$ is the CoC percolation rate (ft/yr) as calculated in Step 2 of Equation Set III.

Step 2

CoC in the vadose zone are subject to several degradation and attenuation processes. This equation considers biodegradation in addition to the parameters of the previous equations. As attenuation processes such as dilution and volatilization are not accounted for in this equation, an estimate of the concentration (C_p) (mg/L) of CoC in the soil pore water necessary to protect ground water is calculated.

where,

$$\mathbf{\log(Cp) = \log(C_{GWsstl}) + \left(\frac{Tc * 0.693}{2.303 * t_{1/2}}\right)}$$

$\mathbf{C_{GWsstl}}$ is the Site-Specific Target Level (mg/L) for CoC in ground water from groundwater fate and transport model or the Risk-based Screening Level as appropriate.
$\mathbf{T_c}$ is the time (days) for contaminant to percolate through the uncontaminated vadose zone soil and reach the ground water as calculated in Step 1 of Equation Set IV.
$\mathbf{t_{1/2}}$ is the biodegradation half-life period of CoC (days) from Table C2.

Equation Set V

Determination of the Site Specific Target Levels for impacted soil

DILUTION/ATTENUATION FACTOR (DAF)

The **Dilution/Attenuation Factor** is a unitless number that expresses the magnitude of dilution and attenuation which occurs after the leachate generated from the soil encounters ground water.

Utilizing a Monte Carlo modeling approach, a range of typical site parameters were evaluated by the Department to determine appropriate Dilution / Attenuation Factors (DAF). Parameters that were considered include: hydraulic conductivity, hydraulic gradient, ground water recharge rates, dimensions of the impacted soil, and aquifer thickness. The following DAFs should be utilized as default values:

For Sandy Soil (hydraulic conductivity > 10^{-4} cm/sec)	DAF = 8
For Clay Soil (hydraulic conductivity $\leq 10^{-4}$ cm/sec)	DAF = 2

SITE SPECIFIC TARGET LEVEL (SSTL)

Determine the site specific target level of the CoC in soil. Equilibrium contaminant partitioning between sorbed and aqueous phases can be described by the following equation:

$$\mathbf{C_{sstl} = Cp * DAF * \frac{(Bd * Koc * fcs) + Wr + f * H'}{(Wr * 1g/cc + Bd)}}$$

where,

$\mathbf{C_{Ssstl}}$ is the Site Specific Target Level (mg/Kg) for the CoC in soil.
$\mathbf{C_p}$ is the concentration of the CoC in soil pore water (mg/L) calculated in Step 2 of Equation Set IV.
DAF is the Dilution/Attenuation Factor (unitless).
$\mathbf{K_{oc}}$ is the Soil organic/water partitioning coefficient (ml/g) from Table C2.
$\mathbf{f_{cs}}$ is the Total organic carbon content in decimal percent of the contaminated soil as calculated in Step 1 of Equation Set I.
f is the air filled porosity (decimal %) calculated in Step 2 of Equation Set I.
$\mathbf{W_r}$ is the residual water content (decimal %) from Figure C2.
1g/cc is the density of water.
$\mathbf{B_d}$ is the bulk density of the soil (g/cc) from Figure C3.

Leachability Input Parameters

South Carolina Department of Health and Environmental Control

Bureau of Land and Waste Management - Underground Storage Tank Program

Site Data

Facility Name: ____ UST Permit # ____________

Input Parameters

Percent Sand in soil	_________	%	**5% < sand < 70%**
Percent Clay in soil	_________	%	**5% < clay < 60%**
DAF	_________		

Worst	Benzene	_________	mg/Kg	C_s
Case	Toluene	_________	mg/Kg	C_s
Soil	Ethylbenzene	_________	mg/Kg	C_s
Analyses	Xylenes	_________	mg/Kg	C_s
	Naphthalene	_________	mg/Kg	C_s
	Other CoC	_________	mg/Kg	C_s
		_________		
		_________		

			Figure
Natural organic carbon content	mg/Kg	f_{oc}	
TPH	mg/Kg	**TPH**	
Porosity	decimal %	ϕ	C1
Residual water content	decimal %	W_r	C2
Bulk density of soil	g/cc	B_d	C3
Soil hydraulic conductivity	cm/sec	K_f	C4
Average annual recharge	cm	H_w	
Wetting front suction (negative number)	cm	H_f	C5
Distance from highest soil contamination to water table	cm	L	
Groundwater SSTL (or RBSL if appropriate)	mg/L	C_{GWsstl}	

List possible human exposure pathways from soil:

1 of ___ pages

Leachability Results and Conclusions

South Carolina Department of Health and Environmental Control

Bureau of Land and Waste Management – Underground Storage Tank Program

Site Data

Facility Name: ____ UST Permit #

Chemical of Concern (Benzene, Naphthalene, etc.) : ____

(Please use a separate form for each Chemical of Concern that exceeds the RBSL in soil.)

Chemical Specific Data

Biodegradation half-life period	days	$t_{1/2}$	Refer to
Soil/water partitioning coefficient	mg/L	K_{oc}	Table
Henry's law constant		**H'**	C2

Results

			Equation Set	Step
Total organic carbon content	decimal %	f_{cs}	I	1
Air filled porosity	decimal %	f	I	2
Infiltration time	seconds	t	II	1
Velocity of water	ft/yr	V_w	II	2
Soil/water distribution coefficient	ml/g	K_d	III	1
CoC percolation rate	ft/yr	V_c	III	2
Time to reach groundwater	days	T_c	IV	1
Concentration to protect groundwater	mg/L	C_p	IV	2
Site specific target level	mg/Kg	C_{Ssstl}	V	

Conclusions

Does concentration of CoC in soil exceed SSTL? Yes __________ No ______________

Risk of human exposure due to contaminated soil Yes __________ No ______________

____ of ___ pages

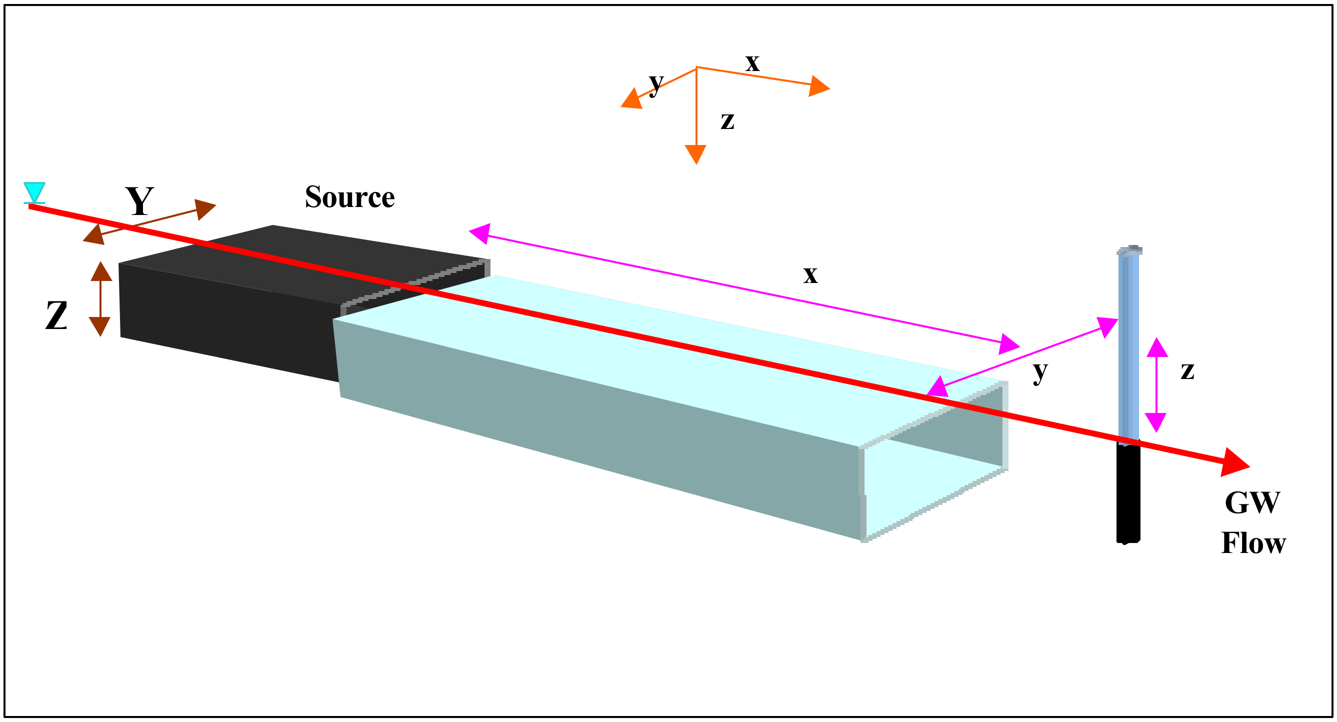
APPENDIX D
DOMENICO’s MODEL

Domenico's Model

Contaminant transport in the saturated or the unsaturated zone can be estimated using the **Domenico Model**. This analytical model utilizes three dimensional dispersion, seepage velocity, and biological degradation principles to predict the spatial and temporal decrease in concentration of CoC away from the source.

The Domenico Model (1987) is based on the following assumptions:

1) One dimensional flow and three dimensional (in two transverse directions and one vertical - downwards direction) dispersion;
2) The medium is isotropic and homogeneous;
3) The source concentration is constant;
4) The areal source is perpendicular to the direction of flow; and
5) decay of the contaminant in the dissolved and adsorbed phases occurs at the same rate resulting in a first order decay rate.



EQUATION 1

This is the general form of the Domenico's Equation. In this equation, the effects of three-dimensional dispersion, one-dimensional uniform flow in the x-direction are considered. The source is considered to be a constant concentration (infinite-mass) areal source of dimension Y and Z (as shown in the Figure D1).

$$\mathbf{C}(x,y,z,t) = \left(\frac{\mathbf{C_0}}{\mathbf{8}}\right) * \exp\left[\left(\frac{x}{2\alpha_x}\right)\left(1-\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right)\right] * erfc\left[\frac{x - vt\sqrt{1+\frac{4\lambda\alpha_x}{v}}}{2\sqrt{\alpha_x vt}}\right] *$$

$$\left\{erf\left[\frac{y+\frac{Y}{2}}{2\sqrt{\alpha_y x}}\right] - erf\left[\frac{y-\frac{Y}{2}}{2\sqrt{\alpha_y x}}\right]\right\} * \left\{erf\left[\frac{z+Z}{2\sqrt{\alpha_z x}}\right] - erf\left[\frac{z-Z}{2\sqrt{\alpha_z x}}\right]\right\}$$

where

C_o is the Concentration of CoC at source (mg/l)
Y is the width of source perpendicular to GW flow (m)
Z is the vertical thickness of source (m)
x is the distance from source to receptor (x-coordinate) (m)
y is the y coordinate of the receptor relative to source (m)
z is the z coordinate of the receptor relative to source (m)
α_x is the longitudinal dispersivity (m) (x/10)
α_y is the transverse dispersivity (m) (α_x/3)
α_z is the vertical dispersivity (m) (α_x/20)
v is the contaminant velocity (m/s)*
erf is the error function**
erfc is the complimentary error function**
λ is the first order decay rate (1/sec)***
t is the time during which contaminant transport takes place (sec)

* If the CoC adsorbs, the contaminant velocity (v) is replaced by the retarded velocity (v/R), where R is the retardation factor in the saturated zone. The Retardation factor can be calculated with the following equation:

$$\mathbf{R} = \mathbf{1} + \frac{\mathbf{K_{oc} * F_{oc} * B_d * 10^{-6}}}{\Phi}$$

where,

K_{oc} is the chemical specific soil/water partitioning coefficient (ml/g) derived from literature.
f_{oc} is the naturally occurring organic carbon (mg/Kg) in soil measured in the saturated zone.
B_d is the Bulk Density (gm/cc).
ϕ is the porosity (decimal %).

** The Error Function and Complimentary Error Function are dimensionless numbers that can be derived from an erf and erfc table. These tables can be found in many hydrogeology textbooks (e.g., Fetter, 1988) .

Please note that: erfc(x) = 1- erf (x); erf(-x) = -erf(x); and erfc(-x) = 1 + erf(x).

*** If the first order decay rates have not been determined on a site-specific basis, the decay rate (λ) shall be assumed to be 0. Site-specific values can be evaluated on the basis of temporal and spatial variation of the CoCs.

EQUATION 2

If the receptor is not located along the x-axis centerline, y and $z \neq 0$ and $\lambda = 0$.

$$\mathbf{C}(x,y,z,t)=\left(\frac{\mathbf{C_0}}{\mathbf{8}}\right)*\,erfc\left[\frac{(\mathrm{x}-\mathrm{vt})}{2\sqrt{\text{á}}_{x}vt}\right]*\left\{erf\left[\frac{\mathrm{y}+\dfrac{\mathbf{Y}}{\mathbf{2}}}{2\sqrt{\text{á}}_{y}x}\right]-erf\left[\frac{\mathrm{y}-\dfrac{\mathbf{Y}}{\mathbf{2}}}{2\sqrt{\text{á}}_{y}x}\right]\right\}*\left\{erf\left[\frac{\mathbf{z}+\mathbf{Z}}{2\sqrt{\text{á}}_{z}x}\right]-erf\left[\frac{\mathbf{z}-\mathbf{Z}}{2\sqrt{\text{á}}_{z}x}\right]\right\}$$

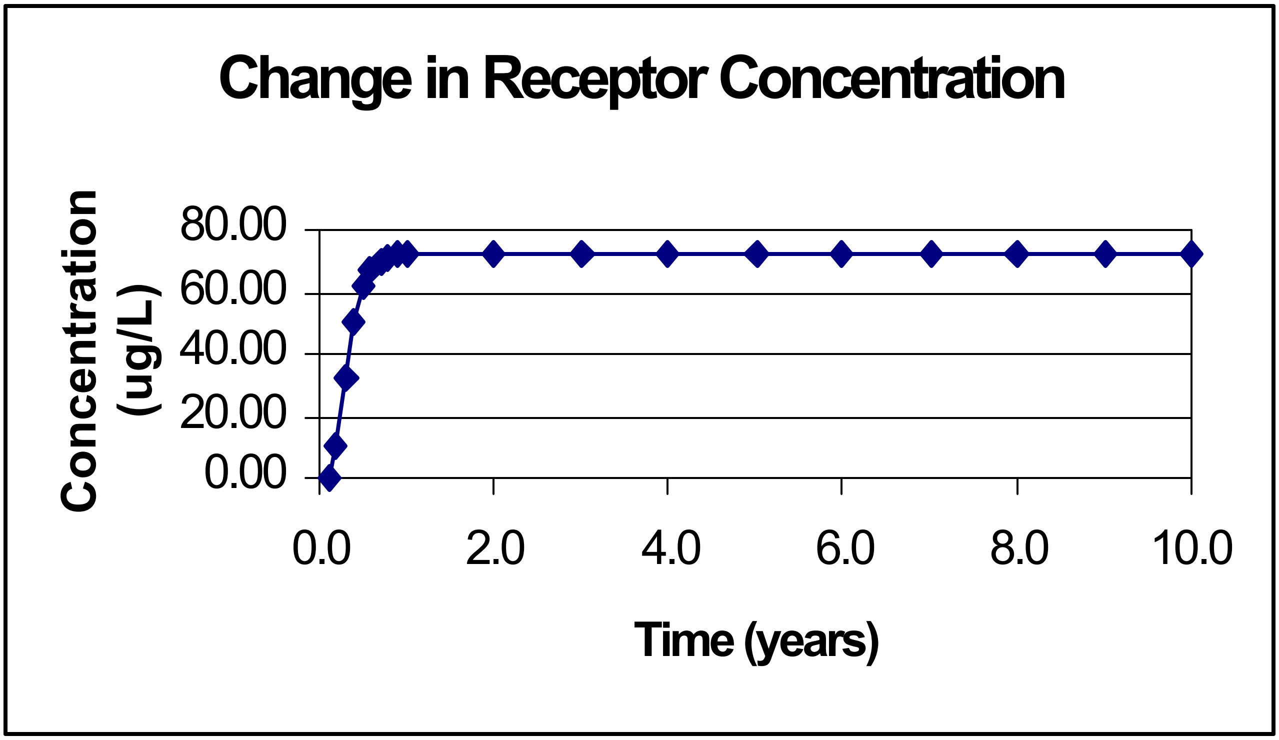
EQUATION 3

Equation 3 should be used if the receptor is located along the centerline (x- axis) and hydraulically down-gradient of the source. In that case, y = z = 0 and $\lambda = 0$.

$$\mathbf{C}(x,0,0,t)=\left(\frac{\mathbf{C_0}}{\mathbf{2}}\right)*\,erfc\left[\frac{(\mathrm{x}-\mathrm{vt})}{2\sqrt{\text{á}}_{x}vt}\right]*\,erf\left[\frac{\mathbf{Y}}{4\sqrt{\text{á}}_{y}x}\right]*\,erf\left[\frac{\mathbf{Z}}{2\sqrt{\text{á}}_{z}x}\right]$$

Variation of a CoC with time is according to an exponential relationship. Figure D2 shows the change in the CoC concentrations for a source of C_0=2 mg/L and with dimensions Y=10m, Z=3m, x=100m, and Vs=1E^{-5}m/s; λ =0 /s. The concentrations for the time t=0 to 10 years were calculated and are tabulated as shown. Based on the graph, we see that the CoC concentrations increase as the time increases, becoming asymptotic at a value of 72.48 µg/L. From this graph, it can be seen that the maximum concentration of 72.48 µg/L can be reached at the receptor for the given continuous source and hydrological conditions after five years.
Data calculated to be used in this example are given in the table below.

Figure D2



Time (Year)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
CoC Conc.(µ/L)	0.16	10.7	32.6	50.6	61.6	67.4	70.2	71.5	72.1	72.3	72.4	72.4	72.5	72.5	72.5	72.5	72.5	72.5	72.5

SSTL CALCULATIONS

Using the Domenico's model, one can calculate the SSTLs for a given source and receptor configuration for each CoC. Knowing the RBSL for a given receptor, the inverse of the Domenico's equation can be used to calculate the SSTL.

The following equation can be used.

$$Csstl=\frac{8*Crbsl}{\exp\left[\left(\frac{x}{2\alpha_x}\right)\left(1-\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right)\right]*erfc\left[\frac{x-vt\sqrt{1+\frac{\lambda\alpha_x}{v}}}{2\sqrt{\alpha_x vt}}\right]*\left\{erf\left[\frac{y+\frac{Y}{2}}{2\sqrt{\alpha_y x}}\right]-erf\left[\frac{y-\frac{Y}{2}}{2\sqrt{\alpha_y x}}\right]\right\}*\left\{erf\left[\frac{z+Z}{2\sqrt{\alpha_z x}}\right]-erf\left[\frac{z-Z}{2\sqrt{\alpha_z x}}\right]\right\}}$$

where

C_{rbsl} is the RBSL concentration for the selected CoC.

Figure D3 shows the change in the CoC concentrations for a source of Y= 10m; Z=3m , x=100m, Vs=1E-5m/s and λ=0 /s. The source concentrations are calculated for a t=0 to 10 years and are plotted as shown. Based on the graph, we can see that the CoC concentrations decrease as the time increases, becoming asymptotic at a value of 137.98 µg/L. From this graph, it can be seen that the minimum SSTL can be established to be at a concentration of 137.98 µg/L after 0.9 year. The data are given in the table below.

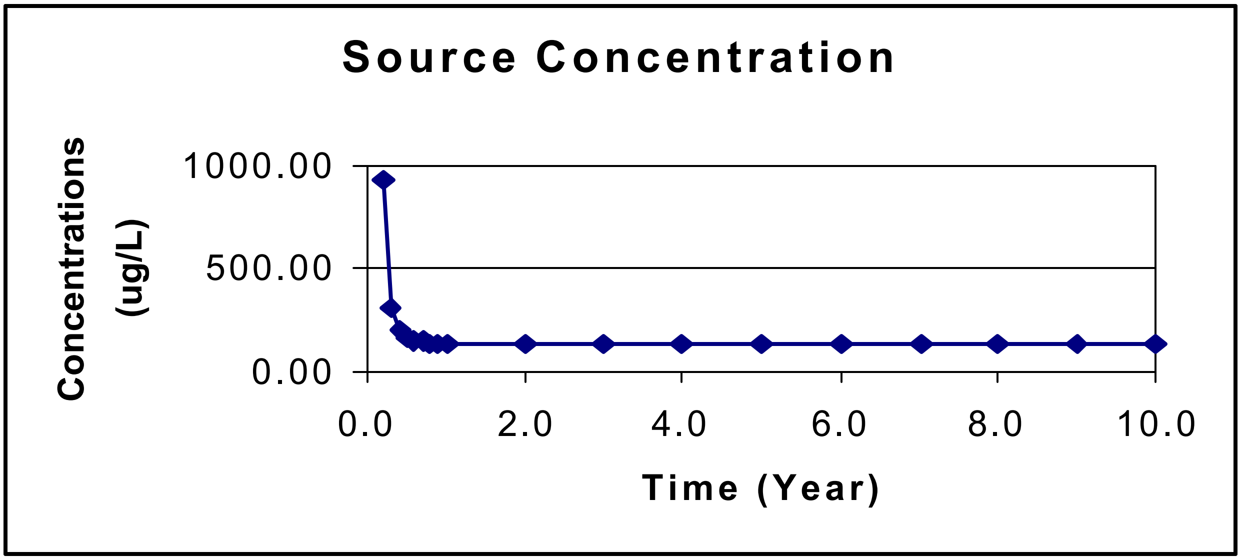


Figure D3

Time (year)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0

CoC Conc.(µ/L)		**936**	**306**	**197**	**162**	**148**	**142**	**139**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**

APPENDIX E
Soil Vapor Model

Soil Vapor Model

In order to identify the amount of contaminant transported from the soil, dissolved liquid and free product phase to the vapor phase, a soil vapor model (modified from Hartman, 1998) is described below. Advection and gaseous diffusion are considered, and contributions from different phases are evaluated based on Fick's equation and assuming equilibrium partitioning conditions.

From the field measurements of the CoC in soil and groundwater, and based on the presence of the free-phase product in soil or above ground water, the soil vapor is estimated and this method can be used as a screening tool. The calculated vapor values can then be compared with the inhalation of vapors pathway RBSLs to assess the vapor concentrations at the UST facility and a protocol to monitor vapor can be developed.

Following equations are used in the development of this model.

Fick's first law:

$$\mathbf{Flux} = \frac{\mathbf{De} * \Delta \mathbf{Csg} * \mathbf{10^3}}{\mathbf{X}}$$

where,

Flux is the rate of movement of a compound per unit area (μg/hr-m^3).
D$_e$ is the effective diffusion coefficient (m^2/hr) in the vadose zone
ΔC$_{sg}$ is the CoC concentration gradient ((μg/L) in the soil vapor
X is the depth below the surface (m)

Under equilibrium conditions the indoor air concentration **Ci** (μg/m^3) due to a constant source can be derived using the following equation:

$$\mathbf{C_i} = \frac{\mathbf{Slab * Flux}}{\mathbf{Height * E}}$$

Slab is the slab attenuation factor (unitless)
Flux is the contaminant flux into the room (μg/hr-m^3).
Height is the room height (m)
E is the indoor air exchange rate (1/hr)

The soil vapor concentration **C$_{sg}$** (μg/L) from soil, dissolved phase and free product contamination is calculated using the methods described below. For a detailed discussion see Hartman, 1998.

for Soil:

$$\mathbf{C_{sg}} = \frac{\mathbf{H * C_{soil} * B_d}}{\mathbf{\theta_w + (K_s * B_d) + (H' * \theta_a)}} \mathbf{* 10^3}$$

from dissolved contamination (without free-phase product):

$$C_{sg} = C_{gw} * H'$$

and from the free-phase product in soil or ground water:

$$C_{sg} = \frac{V_P * MW * mf}{R * T} * 10^6$$

where,

C_{soil} is the concentration of the CoC in soil (mg/Kg)
C_{gw} is the concentration of the CoC in dissolved phase (µg/L)
B_d **is the bulk density in (g/cc)**

ϕ_w is the water porosity (unitless)
ϕ_a is the air porosity (unitless)
H' is the Henry's Law Constant (unitless)
K_{oc} soil water partitioning coefficient in (ml/g)
Vp is the CoC vapor pressure (atmosphere)
MW is the molecular weighting of the CoC in g/mole
mf is the molecular fraction of the CoC in the free phase product
RT is the universal gas constant times temperature (22.4 µL/µmole at 0^0C & 24 µL/µmole at 20^0C)

Total soil vapor can be calculated by adding the above three values for soil, dissolved phase and free product contamination, based on site-specific conditions. Once these values are calculated, they can be compared to the RBSLs for Inhalation of Vapors (Table B5). If the calculated values exceed the RBSLs, then a protocol to monitor the vapor measurements at a facility should be included in the site assessment plan.

APPENDIX F
REMEDIATION BY NATURAL ATTENUATION MODEL

Remediation by Natural Attenuation (RNA) MODEL

This section is added to help determine if the release can be successfully remediated using the natural attenuation of the CoCs under the aquifer conditions. Using the site-specific input parameters collected by field sampling, we can estimate the amount of the assimilative capacity of the aquifer and then the time for assimilation to complete. This is based on simple mass-balance relationship equations, which are given below.

RNA MODEL EQAUTIONS

Volume of the aquifer = **X*Y*Z**
Area of the aquifer extent = **Y*Z**
where,
X, Y and **Z** are the length, width and thickness of the source area (m)

$$K_d = K_{oc} * f_{oc} *(1 \times 10^{-6})$$

where

K_{oc} is the soil organic/water partitioning coefficient (ml/g)
f_{oc} is the natural organic carbon content (mg/Kg) of uncontaminated soil (see data acquisition section)
1×10^{-6} is the conversion from mg/Kg to decimal %

The air filled porosity (**f**) (decimal %) can be approximated using the following equation:

$$f = \phi - W_r$$

where

ϕ is the porosity (decimal %)
W_r is the residual water content (decimal %)

The concentration of liquid phase, C_l (μg/L) is obtained by the equation:

$$C_l = Cs * \frac{Bd + Wr}{(f * H' + Wr + Kd * Bd)}$$

where,

C_S is the concentration of the CoC (mg/Kg) in soil.
B_d is the bulk density of the soil (g/cc)
f is the air filled porosity (decimal %)
H' The Henry's Law Constant (mg/l)/(mg/l)
W_r is the residual water content (decimal %)

And the volume of the liquid $\mathbf{Vol_l}$ (m^3) and Mass of the liquid $\mathbf{Mass_l}$ are obtained by equations:

$$\mathbf{Vol_l = Volume * W_r}$$

$$\mathbf{Mass_l = Vol_l * C_l * 1000}$$

The concentration of vapor phase, $\mathbf{C_v}$ (μ/L) is obtained by the equation:

$$\mathbf{C_v = C_l * H'}$$

And the volume of the vapor $\mathbf{Vol_v}$ (m^3) and Mass of the liquid $\mathbf{Mass_v}$ are obtained by equations:

$$\mathbf{Vol_v = Volume * f}$$

$$\mathbf{Mass_v = Vol_v * C_v * 1000}$$

The concentration of soil phase, $\mathbf{C_{soil}}$ (μg/L) is obtained by the equation:

$$\mathbf{C_{soil} = C_l * K_d}$$

And the sorbed soil can be obtained by:

$$\mathbf{Mass_{sorb} = C_{soil} * B_d * Volume * 1000}$$

Total Mass of the CoC in all three phases:

$$\mathbf{Mass_{Total} = Mass_l + Mass_v + Mass_{sorb}}$$

Infiltration Rate can be obtained by equation:

$$\mathbf{IR = X * Y * H_w * 0.01}$$

From which we can calculate the total mass of the CoC leaching to the groundwater:

$$\mathbf{Mass_{WT} = C_l * IR * 1000}$$

And the time it takes for this to happen is:

$$\mathbf{Time = \frac{Mass_{Total}}{Mass_{WT}}}$$

Assimilative Capacity (mg/L)of the Aquifer based is given by:

$$\mathbf{AC = \frac{Obs.\ Ferrous}{21.8} + \frac{Obs.\ Methane}{0.78} + \frac{Delta\ D.O.}{3.14} + \frac{Delta\ Sulfate}{4.7} + \frac{Delta\ Nitrate}{4.9}}$$

Where,

Obs. Ferrous is the observed ferrous iron concentration at the source area (mg/L)
Obs. Methane is the observed methane concentration at the source area (mg/L)
Delta D.O. is the amount of upgradient Oxygen that exceeds the minimum Oxygen in the source area (mg/L)
Delta Sulfate is the amount of upgradient Sulfate that exceeds the minimum Sulfate in the source area (mg/L)
Delta Nitrate is the amount of upgradient Nitrate that exceeds the minimum Nitrate in the source area (mg/L)

Total liquid flow (liters/Yr) through the aquifer in one year is given by:

Total Flow = Area * Vs * 1000

Where **Vs** is the seepage velocity (m/Yr)

Total Mass (mg) to be removed per year (mg/Yr) can be obtained by:

Total Mass = Total Flow * Assimilative Capacity

Therefore, the **Time for Assimilation** given by:

$$\textbf{Time of Assimilation} = \frac{\textbf{Total Mass}}{\textbf{Mass removed per Year}}$$

APPENDIX G
REFERENCES

References

ASTM, Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites American Society for Testing & Materials, **E1739-95** which may be obtained by contacting ASTM at 1916 Race Street, Philadelphia, PA., 19103-1187 or at (215) 299-5400.

Bene, K. and M. M. Gribb, 1998. Development of Graphical Method for Determining Site-Specific Target Levels for Contaminated Soils, Department of Civil Engineering, University of South Carolina, Final Report submitted to the SCDHEC.

Bene & Gribb, Molly, 2000. Re-evaluation of the Soil Leachability Model, Department of Civil Engineering, University of South Carolina, Final Report submitted to SCDHEC.

Brady, N.C., 1984. The Nature and Properties of Soils. Macmillan Publishing Company.

Buol, S.W., F.D. Hole, and R.J. McCracken, 1980. Soil Genesis & Classification. Iowa State University Press.

Cushman, J.H., 1990. Dynamics of Fluids in Hierarchical Porous Media. Academic Press.

Devinney, J.S., Everett, L.G., Lu, J.C.S, and Stollar, R.L., 1990. Subsurface Migration of Hazardous Wastes. Van Nostrand Reinhold Publishers.

Domenico, P.A., 1987, An analytical model for multidimensional transport of a decaying contaminant species: Journal of Hydrology, V. 91, p.49-58.

Domenico, P.A. and Robbins, G.A., 1985, A new method of contaminant plume analysis: Ground Water, V. 23, No. 4, p.476-485.

Dragun, J., 1988. The Soil Chemistry of Hazardous Materials. Hazardous Materials Control Research Institute, Silver Spring, Maryland.

EPA Region III, Risk-Based Concentration Table that may be obtained through EPA Region III's Internet Website (http://www.epa.gov/reg3hwmd/risk/riskmenu.htm)

Fetter, C.W., 1988. Applied Hydrogeology. Macmillan Publishing Company.

Fetter, C.W., 1993. Contaminant Hydrogeology. Macmillan Publishing Company.

Green, W.H. and Ampt, G.A., 1911. Studies in Soil Physics. I. The flow of air and water through soils. Journal of Agricultural Science 4:1-24.

Gribb, Molly, 1994. Personal Communication. The University of South Carolina, Department of Civil Engineering, Columbia, SC.

Guidance Manual for Risk Assessment Contaminant Fate and Transport Modeling, RG-91, May 1994, Texas Natural Resource Conservation Commission.

Guide for Risk-Based Corrective Action at Petroleum Release Sites, Final Draft, December 27, 1994. American Society for Testing & Materials Emergency Standard ES38-94 (No longer available).

Hartman, B., 1998, The Upward Migration of Vapors, *Lustline Bulletin 27*, Pages 12-15.

Howard, P.H., Boethling, R.S., Jarvis, W.F., Meylan, W.M., and Michalenko, E.M. 1991. Handbook of Environmental Degradation Rates. Lewis Publishers.

Knox, R.C., Sabatini, D.A., and Canter, L.W., 1993. Subsurface Transport and Fate Processes. Lewis Publishers.

Luckner, L. and Schestakow, W.M., 1991. Migration Processes in the Soil and Groundwater Zone. Lewis Publishers.

Menatti, J.A., Marrin, D.L., and Anderson, M.D., 1994. Fate and Transport Modeling of Diesel Fuel Contamination in the Vadose Zone. In Clabrese and Hospechi (eds.), Hydrocarbon Contaminated Soils and Groundwater, pp. 97-111. AEHS Publishers.

Montgomery, J.H. and Welkom, L.M., 1991. Groundwater Chemicals Desk Reference. Lewis Publishers.

Montgomery, J.H., 1991. Groundwater Chemicals Desk Reference Volume 2. Lewis Publishers.

Mualem, Y., 1976. A Catalogue of the Hydraulic Properties of Unsaturated Soils. Israel Institute of Technology Hydrodynamics & Hydraulic Laboratory.

Rawls, W.J. and Brakensiek, D.L., 1989. Estimation of Soil Water Retention and Hydraulic Properties. from H.J. Morel-Seytoux (ed.), 1989. Unsaturated Flow in Hydrologic Modeling. Kluwer Academic Publishers

South Carolina Department of Health and Environmental Control, March 2000. Analytical Methodology for Groundwater and Soil Assessment Guidelines, Initial Ground-Water Assessment Guidance, Tier 1 Assessment Guidance, Tier 2 Assessment Guidance and Corrective Action Guidance Documents.